V. HYDROGEOLOGY

Geologic conditions and processes and the local climate control virtually all aspects of the occurrence and movement of groundwater. Fundamentally, lithology and structure of the rocks and sediments determine the existence and character of openings in which groundwater occurs. Geologic processes, including faulting, folding, volcanism, and weathering, significantly affect groundwater occurrence and movement. The ability of different rocks and sediments to store, transmit, and adequately supply large-scale water uses varies markedly. Thus, rock types can be differentiated primarily based on their water-bearing and hydraulic characteristics.

For the Arroyo Grande - Nipomo Mesa area, the rocks and sediments described in Chapter II can be grouped into two units. The semi-consolidated to unconsolidated sediments form one unit, creating the groundwater basin, and the basement complex, volcanic, and consolidated sedimentary rocks, collectively referred to by the relative term bedrock, form the second unit. The bedrock possesses only limited ability to store and transmit groundwater. In a hydrogeologic sense, it can be considered as providing boundaries for the sediment-filled groundwater basin. However, groundwater does move from the bedrock uplands to the groundwater basin and from the basin into the underlying bedrock, and together they form a complex, interrelated two-media groundwater system.

Santa Maria Groundwater Basin

The Santa Maria Groundwater Basin underlies more than 280 square miles (181,790 acres) in the southwestern corner of San Luis Obispo County and the northwestern corner of Santa Barbara County. The groundwater basin formed within the geologic depositional Pismo and Santa Maria Basins separated by the Santa Maria River fault (described in Chapter II) and the present limits of the groundwater basin were established in mid-Pleistocene time. This study considered only the portion of the basin within San Luis Obispo County, about 61,220 acres. About 120,570 acres, or 66 percent of the area overlying Santa Maria Basin, is located in Santa Barbara County.

Within the study area, the Santa Maria Basin consists of the main basin, Santa Maria, and three subbasins, Arroyo Grande Valley, Pismo Creek Valley, and Nipomo Valley. The main basin underlies about 49,910 acres and the subbasins underlie a total of 11,310 acres. Both the surface area and the underlying permeable sediments form the basin. In San Luis Obispo County, the main Santa Maria Basin underlies the coastal plains of Santa Maria River and Arroyo Grande and Pismo Creeks interposed by Tri-Cities and Nipomo Mesas.

Groundwater Basin Boundaries

The boundaries of the Santa Maria Basin, as defined in this study, are shown in Plate 10. The boundaries were delineated based on mapped surface limits of Quaternary deposits and the Wilmar Avenue fault (Hall and Corbato, 1967, map scale 1:48,000; Hall, 1973, map scale 1:48,000; Hall, 1978b, map scale 1:24,00; Dibblee, 1989 and 1994, map scales 1:24,000; and Hanson et al., 1994, map scale 1:24,000). The boundaries represent the surface expression of the basin and do not imply that the boundaries extend vertically downward in a third dimension.[1] Arbitrary boundaries for the basin are eliminated by using mapped surface geologic contacts and faults.[2]

Santa Maria Basin. Within San Luis Obispo County, the main basin is bounded on the north and east by the Wilmar Avenue fault, separating it from Arroyo Grande Valley, Pismo Creek Valley, and Nipomo Valley Subbasins. The western boundary of the groundwater basin is the Pacific Ocean, although the basin is hydraulically continuous offshore beneath the ocean. On the south, the county line with Santa Barbara County forms a political boundary within the basin, but it has no hydraulically physical significance to the groundwater system.

As mentioned in Chapter I, the main groundwater basin was divided and evaluated based on the hydrologic boundaries,[3] because of the need to provide applicable information for San Luis Obispo County. The divisions of the main basin are: (1) the Tri-Cities Mesa - Arroyo Grande Plain portion, that includes the lower Pismo Creek portion of the basin lying within Pismo HSA and the Tri-Cities Mesa, Arroyo Grande Plain, and Los Berros Creek portions of the basin lying within Oceano HSA;[4] (2) the Nipomo Mesa portion of the basin, lying entirely within Nipomo Mesa HSA; and (3) the Santa Maria Valley portion of the basin, lying within Guadalupe HA.

Arroyo Grande Valley Subbasin. The Arroyo Grande Valley Subbasin lies within the Oceano HSA in the San Luis Range at the northwestern edge of the main Santa Maria Basin. The subbasin is the alluvial-filled Arroyo Grande Valley, drained by Arroyo Grande Creek and its tributaries from below Lopez Dam to its southern boundary at the Wilmar Avenue fault, which separates it from the main basin. It underlies about 3,860 acres. The boundaries coincide with the alluvial contact with older sedimentary rocks and basement complex between Lopez Dam and the Wilmar Avenue fault.

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[1]Mapping of the basin boundary in three dimensions would require extensive subsurface investigation and is beyond the scope of this study.

[2]Boundaries for the Santa Maria Basin in existing published studies are not based on mapped geologic contacts and faults and are arbitrary.

[3]The division of the groundwater basin based on the hydrologic boundaries in this report is not the same as the divisions used by others, such as the storage units of the USGS. Geographic names were used for the divisions of the groundwater basin because, with the exception of Nipomo Mesa, the basin underlies only portions of the hydrologic areas.

[4]Some discussions providing more detailed information may specifically address the lower Pismo Creek, Los Berros Creek, Tri-Cities Mesa, or Arroyo Grande Plain portions of this division of the basin.

Pismo Creek Valley Subbasin. The Pismo Creek Valley Subbasin lies within the Pismo HSA in the San Luis Range at the northern edge of the main groundwater basin. The subbasin is the alluvial-filled valley of Price Canyon, which is drained by Pismo Creek and its tributaries. It underlies about 1,220 acres. The boundaries of the subbasin coincide with the alluvial contact with older sedimentary rocks and the Obispo Formation. The northern boundary of the subbasin coincides with the southern boundary of Edna Basin, where bedrock narrows the creek channel, and the southern boundary of the subbasin is along the Wilmar Avenue fault.

Nipomo Valley Subbasin. The Nipomo Valley Subbasin underlies about 6,230 acres within the Guadalupe HA. This gently southwest-sloping upland area east of Highway 101 is drained by Nipomo Creek flowing perennially along the western edge of the valley to its confluence with the Santa Maria River. The subbasin is bounded mainly by the contact of the older alluvium and Orcutt Formation with older geologic units and is separated from the main basin on the west by the Wilmar Avenue fault. The southern boundary of the subbasin, which is the watershed boundary for Nipomo Creek, is the study area boundary.

Base of Groundwater Basin

The potentially water-bearing basin-fill sediments are underlain by bedrock. Elevation contours of the bedrock surface that forms the base of the groundwater basin are shown in Plate 11. The base contours were developed from interpretation of available water and oil well lithologs and electric logs, and previously published cross-sections and base contour maps. The base of the main groundwater basin rises from about 1,500 feet below msl under the Santa Maria River to about 200 feet above msl under the northeastern edge of Nipomo Mesa. The base contours reflect vertical displacement of the bedrock across the Oceano and Santa Maria River faults.

The base of the alluvial sediments in Arroyo Grande Valley Subbasin rises from about msl at Wilmar Avenue fault to almost 350 feet above msl at Lopez Dam.

In Pismo Creek Valley Subbasin near Wilmar Avenue fault, the base of the alluvial sediments ranges from about 40 feet below msl to msl. Data for the rest of the subbasin are unavailable.

In Nipomo Valley Subbasin, the base of the older alluvial sediments ranges from less than 200 feet above msl near Highway 166 to between 275 and 300 feet above msl east of Thompson Avenue. The bedrock is vertically displaced across the Wilmar Avenue fault (Plate 5).

Occurrence of Groundwater

Groundwater occurs within the pore spaces in the sedimentary deposits filling the basin. In the main basin, these deposits include the Squire Member of the Pismo Formation; the Careaga, Paso Robles, and Orcutt Formations; alluvium; and dune sands. They sequentially fill the basin to a maximum thickness of about 1,600 feet from oldest to youngest. The Pismo and Careaga Formations are found only within their respective geologic depositional basins.

With the exception of the dune sands, the basin-fill sediments were deposited by water in either fluvial, marginal marine, or shallow marine environments, whose exact locations varied widely depending on the relative positions of land masses, shorelines, and streams at a given point in geologic time. Consequently, a heterogeneous array of sands, gravels, boulders, silts, and clays, occurs in layers or lenses of varying composition, texture, and thickness. The varied lithologic layers or lenses are discontinuous.

Santa Maria Basin. The main Santa Maria Basin is considered a composite aquifer system of unconfined conditions, with localized semi-confined to confined conditions and perched zones.[5] Discontinuous clayey layers separate the multiple aquifer zones (see Plates 3-5). Confinement may be restricted to the deeper aquifer zones (Cleath & Associates, 1996a).

Worts (1951) demarcated a large area, extending inland for about 6 miles beneath the Oso Flaco District and Santa Maria Valley, as containing water confined by fine-grained sediments in the upper part of the alluvium. However, he also stated that the continuity of the clay beds across the west end is not conclusive. Historically, some wells in this region were flowing. Today, flowing wells may occur only adjacent to the coast.

Holocene alluvium through upper Pliocene sediments constitute the principal groundwater reservoir of the basin. The most productive and developed aquifers are in the alluvium and Paso Robles Formation. Some wells in the groundwater basin produce from either the alluvium or the Paso Robles Formation only, and others produce from both deposits. Aquifers in the Squire Member of the Pismo Formation and the Careaga Formation have, over time, become more important. Wells typically produce from either the Careaga Formation or the Squire Member in combination with the Paso Robles Formation

Both the recent dune sands and parts of the older dune sands are largely unsaturated, but are important for rapidly infiltrating recharge waters to the saturated zone. The recent dune sands are not known to be tapped by wells. The older dune sands are penetrated by wells that produce primarily from the underlying formations.

Perched Groundwater Zones. Localized zones of saturation may exist above the main water table. This situation occurs where clay lenses within the vadose zone intercept downward percolating water and cause some of it to accumulate above the lenses. The upper surface of the groundwater in these cases is called a perched water table.

Local zones of perched groundwater occur within the older dune sands on the mesa, but not continuously across the mesa. The Morro Group (1990) found that the ponds at the upper end of Black Lake Canyon are perched groundwater. The dune lakes, south of Oceano, and Oso Flaco and Little Oso Flaco Lakes are surface water bodies hydraulically connected to perched

[5]In areas of complex geology, the distinction between confined, semi-confined, and unconfined is very difficult or impossible to make (Davis and DeWiest, 1966, p. 45).

groundwater. Also, minor bodies of perched and semi-perched groundwater are present locally in the coastal alluvial deposits.

Some wells produce small quantities of groundwater from these perched zones, but they are typically not dependable sources of supply, and are greatly affected by variable hydrologic conditions. Because perched groundwater is not a dependable source of supply, it is not considered for water supply planning purposes in this report.

Arroyo Grande Valley Subbasin. Groundwater occurs in the alluvium. Thickness of the alluvium averages about 100 feet. Maximum thickness of the alluvium is about 175 feet just above the confluence of Tar Spring and Arroyo Grande Creeks (Goss and Reed, 1969, p. 72). Groundwater is mainly unconfined. In some parts of the subbasin, the alluvium may be saturated only during rainfall.

Pismo Creek Valley Subbasin. Groundwater occurs in the alluvium. Thickness of the alluvium ranges from negligible to about 60 feet near the southern boundary. Groundwater is unconfined. In some parts of the subbasin, the alluvium may be saturated only during rainfall.

Nipomo Valley Subbasin. Groundwater occurs in the older alluvium, which covers the floor of the valley up to about 90 feet thick, thinning to negligible thickness toward the eastern edges of the subbasin. Groundwater in the older alluvium is unconfined with local semi-perched conditions. The older alluvium stores a notable amount of groundwater and continues to supply some wells, although the older alluvium may be saturated only during rainfall at the eastern edges of the subbasin. The bedrock formations underlying the older alluvium have, over time, become a more important source of groundwater supply in the subbasin. These formations are discussed later in this chapter, under the section "Groundwater in Bedrock."

Well Yields and Depths. The yields and depths of wells for the different groundwater basin deposits are summarized from the well completion reports and presented in Table 15.

By means of "schematic box plots" (Tukey, 1977), Figure 11 depicts well yields, as reported on available well completion reports. These plots display the main aspects of the data: (1) the middle 50 percent of the data values, which are between the values in the upper 75 and lower 25 percent quartiles; (2) the whiskers indicating the range of extreme values outside an interval of the interquartile range; and (3) values outside the whisker range, plotted individually as outliers.[6] Extreme and outlier values play important roles in providing information on a data set.

The highest yields are generally from wells producing from the alluvium and the Paso Robles Formation in Tri-Cities Mesa and Santa Maria Valley. Yields of wells in Nipomo Mesa are shown separately for wells north of the Santa Maria River fault and for those south of the fault.

[6]Extreme values extend to within 1.5 times the interquartile range; outliers are within 1.5 to 3.0 times the interquartile range and greater than 3 times the interquartile range (Kleiner & Graedel, 1980).

TABLE 15
WELL DEPTHS AND YIELDS OF PRODUCTION AQUIFERS*

Water-bearing Deposit	Division Within Basin	Well Depths, in feet		Well Yields, in gallons per minute	
		Median	Range	Median	Range
Alluvium	Arroyo Grande Plain	100	25 - 155	60	10 - 1,700
	Los Berros Creek	80	60 - 100	70	25 - 250
	Santa Maria Valley	175	91 - 222	50	20 - 2,300
	Arroyo Grande Valley Subbasin	95	38 - 155	60	13-500
Paso Robles Formation	Tri-Cities Mesa	140	27 - 250	235	10 - 2,500
	Nipomo Mesa**	310	60 - 600	45	½ - 1,525
	Santa Maria Valley	420	193 - 685	1,580	270 - 2,000
Alluvium and Paso Robles Formation	Santa Maria Valley	310	180 - 518	1,650	20 - 1,950
Paso Robles and Careaga Formations	Nipomo Mesa	490	284 - 810	430	12 - 1,500
	Santa Maria Valley	790	741 - 832	-	-
Paso Robles Fm. and Squire Member	Tri-Cities Mesa	460	300 - 600	1,070	150 - 2,000
Squire Member	Tri-Cities Mesa	480	295 - 607	270	90 - 1000

*The smaller well yields are typically from residential wells.
**Dry holes are encountered northeast of the Santa Maria River fault (northeast of Pomeroy Road).

The figure shows the large difference in well yields found on opposite sides of the Santa Maria River fault. For wells on the north side of the fault, the median yield is 10 gallons per minute and for wells on the south side of the fault, the median yield is 210 gallons per minute.

Data are limited for Pismo Creek Valley Subbasin, with only two well completion reports listing well yields. Those yields were 25 and 30 gallons per minute.

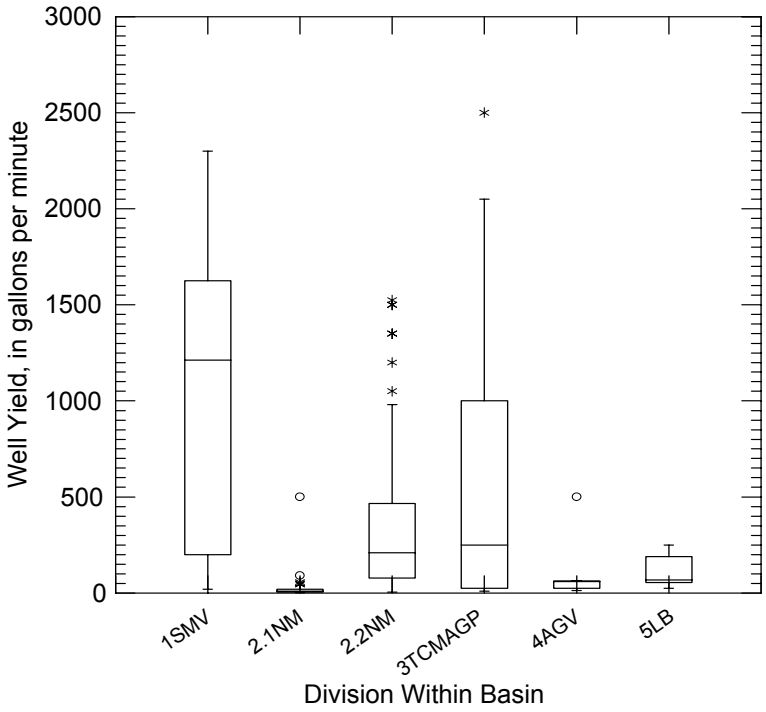
In Nipomo Valley Subbasin, a few older wells are perforated only in the older alluvium, are less than 80 feet deep, and have yields of 20 to 30 gallons per minute.

Recharge and Discharge

Santa Maria Basin. Groundwater in the main Santa Maria Basin is recharged from both natural and incidental sources. Stream infiltration, deep percolation of direct precipitation, and subsurface inflow are sources of natural recharge.

Stream infiltration from Arroyo Grande Creek, regulated by Lopez Dam since 1969, recharges the Tri-Cities Mesa - Arroyo Grande Plain portion of the main groundwater basin. Lawrance, Fisk & McFarland, Inc. (1985c) reported that the Tri-Cities Mesa part of the groundwater basin recharges rapidly during wet years and depletes rapidly during dry periods and that whenever

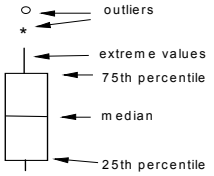
FIGURE 11 - YIELD OF WELLS IN SANTA MARIA GROUNDWATER BASIN*



EXPLANATION

1SMV: Santa Maria Valley
2.1NM: Nipomo Mesa, north of Santa Maria River Fault
2.2NM: Nipomo Mesa, south of Santa Maria River Fault
3TCMAGP: Tri-Cities Mesa - Arroyo Grande Plain
4AGV: Arroyo Grande Valley Subbasin
5LB: Los Berros Creek

*The smaller yields are typically from residential wells.



natural water supply is sufficient for Lopez Reservoir to fill, the supply has also been sufficient to recharge Tri-Cities Mesa.

Stream infiltration from Pismo Creek, which is unregulated, recharges the northern part of the Tri-Cities Mesa - Arroyo Grande Plain portion of the main Santa Maria Basin.

The Santa Maria River, regulated in part by Twitchell Dam since 1958, recharges the Santa Maria Valley portion of the main groundwater basin. Each year's recharge from the Santa Maria River travels away from the river as a mound. At a distance from the river, there may be a time lag of up to about a year for groundwater elevations in Santa Maria Valley to be affected.

Both Lopez and Twitchell Dams regulate surface releases to maximize groundwater recharge and

provide flood control. The amount of recharge is related to the availability of streamflow.

Recharge to the groundwater basin by deep percolation of direct precipitation is intermittent, occurring during and immediately following periods of sufficient precipitation and varying from year to year depending on amount and frequency of rainfall, air temperature, land use, and other factors. Because no surface waters flow into Nipomo Mesa, deep percolation of direct precipitation is the major source of natural recharge for the mesa. Interdunal depressions trap runoff in the mesa, thereby enhancing infiltration and percolation of rainfall.

Subsurface inflows also recharge the main groundwater basin. The Tri-Cities Mesa - Arroyo Grande Plain portion of the basin is recharged by subsurface inflows from Arroyo Grande Valley and Pismo Creek Valley Subbasins. In addition, Tri-Cities Mesa is recharged by subsurface inflow from the adjoining San Luis Range, and Arroyo Grande Plain is recharged by subsurface inflow from the Nipomo Mesa portion of the basin. The Nipomo Mesa portion of the main basin may be recharged by subsurface inflow from the adjoining Nipomo Valley Subbasin; however, the potential hydraulic continuity across the Wilmar Avenue fault is unknown (discussed under *Faults* in the next section). Nipomo Mesa can also be recharged by subsurface inflow from the Santa Maria Valley portion of the basin within San Luis Obispo County (discussed in the next section).[7] The Santa Maria Valley portion of the main basin within the study area is recharged by subsurface inflow from the upstream part of the groundwater basin, outside the study area, and may also be recharged by subsurface inflow from the southern end of Nipomo Valley Subbasin; however, the potential hydraulic continuity across the Wilmar Avenue fault is unknown.

Deep percolation of urban and agricultural return water, treated wastewater returns, and septic tank effluent are sources of incidental recharge to the groundwater basin.

Groundwater discharges from the basin as subsurface outflow to the Pacific Ocean. Discharge also consists of evapotranspiration losses, rising water, springflow, and percolation into the underlying bedrock. At the Dune Lakes and Oso Flaco Lakes, groundwater discharges as diffuse upward leakage. Extractions from wells for beneficial consumptive uses are a significant source of discharge from the basin.

Arroyo Grande Valley Subbasin. Groundwater is recharged by stream infiltration from surface flows in Arroyo Grande Creek and its tributaries, deep percolation of direct precipitation, deep percolation of applied water and septic tank effluent, and subsurface inflows from the San Luis Range. Discharge from the subbasin consists of surface and subsurface outflow to the main Santa Maria Basin, evapotranspiration losses, and extractions from wells.

Pismo Creek Valley Subbasin. Groundwater is recharged by stream infiltration from surface

[7]Subsurface inflows from Santa Maria Valley into Nipomo Mesa will occur whenever the groundwater elevations beneath Nipomo Mesa are below those of Santa Maria Valley, altering the hydraulic gradient and direction of flow.

flows in Pismo Creek and its tributaries, deep percolation of direct precipitation, deep percolation of applied water and septic tank effluent, and subsurface inflows from Edna Basin and the San Luis Range. Discharge from the subbasin consists of surface and subsurface outflows to the main Santa Maria Basin, evapotranspiration losses, and extractions from a few small wells.

Nipomo Valley Subbasin. Groundwater is recharged by stream infiltration from surface flows in Nipomo Creek and its tributaries, deep percolation of direct precipitation, deep percolation of applied water and septic tank effluent, and subsurface inflows from Temattate Ridge. Groundwater is discharged from the subbasin by well extractions, evapotranspiration, and subsurface outflows to the main Santa Maria Basin; however, the potential hydraulic continuity across the Wilmar Avenue fault is unknown.

Groundwater Elevations and Movement

Contour maps of elevations of the groundwater surface in a basin show not only the elevation to which the basin is filled, but also the direction in which the water is moving and the slope producing the movement. The contours connect points of equal hydraulic head or equal altitude of the water surface. The direction of groundwater movement is perpendicular to the contours. The rate of movement is proportional to the hydraulic gradient and the permeability of the deposits. Contour maps of groundwater elevations show areal conditions as of a specific date. By comparing maps for different times, any changes in direction of groundwater movement or storage that may have occurred during the interval between maps can be determined.

The shape of the contours is influenced chiefly by recharge and is modified by conditions such as changes in aquifer hydraulic properties and cross-sectional area of sediments and by faults or other structural impediments or barriers. The natural flow patterns become distorted in areas of large-scale groundwater development.

For this study, groundwater elevation contour maps were prepared for three specific times, the springs of 1975, 1985, and 1995 (Plates 12-14).[8] Groundwater level measurement records were compiled from monitoring programs conducted by San Luis Obispo County; Santa Maria Water Conservation District; USGS; Santa Barbara County Public Works Department, Water Resources Division; and the Department. In addition, fragmentary records from well owners, well drillers, and others were included. Static (nonpumping) depth to water measurements from wells throughout the study area were used. The depths to water were subtracted from the reference elevation of the well (generally one-half foot to one foot above the land surface) to obtain the groundwater elevation, then plotted on a map and contoured.

[8]Insufficient groundwater level measurements were available to construct a groundwater elevation contour map for spring 1984, the beginning water year of the hydrologic base period; therefore, a map was constructed for spring 1985.

At the request of San Luis Obispo County, a spring 2000 groundwater elevation contour map was prepared and is Plate A1 in the Addendum attached at the back of this report.

Several important points need to be noted. Most of the wells are perforated continuously in multiple aquifers.[9] Thus, the contours do not reflect the groundwater elevation of a single aquifer, but represent the surface of the principal groundwater body. Perched groundwater levels were not used in making the maps. Well locations and reference elevations are from field descriptions of the locations as plotted on USGS 7.5-minute quadrangles.[10] Reference elevations were approximated using either the 7.5-minute quadrangles or, where available, digital aerial surveys at five- or two-foot contour intervals. The seawater intrusion wells along the coast and a few other wells in the study area have surveyed reference elevations. Also, monitored wells are not distributed evenly throughout the study area, creating data gaps. Contour lines were interpolated in these areas. Data gaps increased over time as fewer wells were monitored.

The springs of 1975, 1985, and 1995 represent times of differing hydrologic conditions. Water year 1975 had almost normal precipitation, with the Tri-Cities Mesa - Arroyo Grande Plain receiving about 80 percent of the long-term average[11] and Nipomo Mesa and Santa Maria Valley receiving about 90 percent of the long-term average. Water year 1985 was a dry year, with Tri-Cities Mesa - Arroyo Grande Plain receiving 55 percent of the long-term average; Nipomo Mesa, 77 percent; and Santa Maria Valley, 64 percent. Water year 1995 was a wet year, with Tri-Cities Mesa - Arroyo Grande Plain receiving 181 percent of the long-term average; Nipomo Mesa, 191 percent; and Santa Maria Valley, 194 percent.

The shape of the groundwater elevation contours on Plates 12-14 shows that groundwater of the principal water body moves seaward to the Pacific Ocean in a generally westerly or west-northwesterly direction. The plates also show that coastal groundwater elevations were above msl and outflow from the basin to the ocean was occurring, apparently precluding any sea water intrusion along the coast.

Faults. Faults can impede groundwater flow, serve as conduits for flow, or not affect flow, depending on degree of fracturing, displacement, and nature of the material in the fault zone. Faulting may also change the geometry of the basin, as has occurred in the Santa Maria Basin.

The Santa Maria River fault may affect groundwater flow in parts of the basin.

In Arroyo Grande Plain, the elevation contours are shown crossing the Santa Maria River fault, because with the available data, it is not possible to determine if the fault is a groundwater flow barrier or impediment along this segment. Wells drilled in Arroyo Grande Plain are shallow,

[9]Well completion reports are not available for many of the wells that are monitored for depth to groundwater. Some wells have information only on the total depth of the well and not the perforated intervals.

[10]In 2000, San Luis Obispo County located the wells in their monitoring program using GPS (Global Positioning System). Unrectifiable problems with the GPS data resulted in erroneous well locations and elevations and thus could not be used in this study.

[11]Long-term averages for precipitation stations represent period of record through water year 2000 for the station.

producing from the alluvium. No wells are monitored on the southwest side of the fault. The fault may be a barrier to flow in the older formations, but flow may occur across the fault in the alluvium. Displacement across the fault is not as great at the coast as it is along the segment of the fault east of Highway 1 to about a mile east of Zenon Way.

From east of Highway 1 to about a mile east of Zenon Way, significant differences are found in groundwater elevations on opposite sides of the Santa Maria River fault. The fault appears to be a barrier or impediment to groundwater flow in the formations below the older dune sands; however, groundwater levels are in the older dune sands on the north side of the fault and groundwater may be able to cascade over the fault along this segment.

Groundwater elevations are similar on opposite sides of the Santa Maria River fault along the segment near the head of Black Lake Canyon (north of Willow Road to about a mile east of Zenon Way). Along this segment of the fault and to the southeast, faulting has been postulated as bedrock steps (Hanson, et al., 1994), rather than a single fault (Plate 5 of this report). Data are not available to determine what impact the nature of the faulting has on hydraulic continuity across the fault and thus the contours are not extended across the fault.

From south of Willow Road to Joshua Street, water level measurements are not available in wells on the northerly side of the Santa Maria River fault, except for a few level measurements for wells near Joshua Street. The contours are dashed on the plates. As mentioned above, hydraulic continuity across the fault is unknown.

Previous studies did not show the Oceano fault affecting groundwater flow. With the data available for this study, it could not be determined if the fault affects groundwater flow. Because the basin-fill deposits are the same on opposite sides of the fault (Santa Maria Depositional Basin) and have similar hydraulic properties, the fault may have no impact.

The Wilmar Avenue fault does not affect groundwater flow in the alluvium from the Arroyo Grande Valley and Pismo Creek Valley Subbasins to the main basin. Data are not available to determine whether the fault impacts flow from Nipomo Valley Subbasin to the main basin.

Studies are needed to determine more precisely the location of the Santa Maria River fault and its impact and that of the Oceano fault on groundwater flow within the main basin. In addition, the impact of the Wilmar Avenue fault on groundwater flow needs to be assessed.

Spring 1975 Groundwater Elevation Contours. Groundwater elevations in spring 1975, shown on Plate 12, ranged from about 10 to 20 feet above msl along the coast to 350 feet above msl in Arroyo Grande Valley Subbasin, just below Lopez Dam and to 400 feet above msl in Nipomo Valley Subbasin. Groundwater elevations in Tri-Cities Mesa - Arroyo Grande Plain are largely affected by stream infiltration from Arroyo Grande Creek and elevations in Santa Maria Valley by stream infiltration from the Santa Maria River.

A gradient of about 50 feet per mile was nearly uniform as groundwater moved southwesterly down Arroyo Grande Valley Subbasin. The gradient distinctly steepened south of Highway 101, as groundwater flowed out into the main basin. The permeability of the deposits increases in this area, allowing substantial infiltration and percolation (Hoover & Associates, Inc., 1985b). The groundwater gradient greatly flattened to about 5 to 10 feet per mile as groundwater moved westerly toward the ocean under Tri-Cities Mesa-Arroyo Grande Plain.

Groundwater conditions in 1975 in Nipomo Mesa indicate that groundwater, south of the Santa Maria River fault, moved in a west-northwesterly direction across the mesa to the ocean at a gradient generally between five and 10 feet per mile. In northern Nipomo Mesa, east of Highway 1 and north of the Santa Maria River fault, groundwater elevations indicate flow from the mesa into the Arroyo Grande Plain. Also, small pumping depressions were present south of Black Lake Canyon, along Willow Road, and near Division Street.

Near Zenon Way north of the Santa Maria River fault, the contours show a small pumping depression, based on a level measurement from one well. This well has always had low groundwater elevations. No well completion report is available for this well, but a nearby well with a report shows that sediments in this part of the basin are low-yielding, largely clays and shales. The groundwater elevation in this well dropped about 15 feet between spring 1975 and spring 1995. Cleath & Associates (1994) also reported the existence of lower groundwater elevations in this part of the basin.

In Santa Maria Valley, the general direction of groundwater flow was westerly and west-northwesterly from near Highway 101 to the ocean. The gradient was steep near Highway 101, at about 25 feet per mile, then flattened markedly to about 2.5 feet per mile across the center of the valley, and increased slightly to about six feet per mile from near Highway 1 to the ocean.

As indicated by the contours on Plate 12, groundwater flowed southwesterly in Nipomo Valley Subbasin. Groundwater elevations in the subbasin ranged from about 250 to 400 feet above msl. A groundwater high occurs roughly along the watershed divide between Los Berros Creek and Nipomo Valley; the high differentiates groundwater moving toward the alluvial aquifer of Los Berros Creek from groundwater flowing into Nipomo Valley (Cleath & Associates, 1995).

The county does not monitor groundwater levels in wells in the Pismo Creek Valley Subbasin. No data were available to determine groundwater elevations in this subbasin in 1975. Wells in this part of the basin need to be included in the county's monitoring program. The selection of wells to be included is beyond the scope of this study.

Spring 1985 Groundwater Elevation Contours. Plate 13 shows spring 1985 groundwater elevation contours. Groundwater conditions were generally similar to those in spring 1975, although water year 1985 was a dry year. The hydraulic gradient in Tri-Cities Mesa-Arroyo Grande Plain flattened slightly compared to that in 1975. In Nipomo Mesa, the hydraulic gradient in the center of the mesa markedly flattened compared to that in 1975, about 2.5 feet per

mile. The local depressions in Nipomo Mesa were in the same locations, but were slightly larger than those of 1975. The depression near Division Street extended slightly into Santa Maria Valley and groundwater was flowing from the valley into the mesa. In Santa Maria Valley, groundwater elevations were slightly higher than 1975 elevations and the hydraulic gradient was about seven feet per mile across the valley. The higher elevations and thus increased groundwater in storage were the result of the substantial stream infiltration from the Santa Maria River in the 1983 wet year, when flows were about 700 percent of normal, and from Twitchell Reservoir releases in 1984.

Groundwater elevations were slightly lower than those in 1975 in Arroyo Grande Valley and Nipomo Valley Subbasins, reflecting the dry year.

In Pismo Creek Valley Subbasin, a static water level measurement was reported on one well completion report for a well drilled in spring 1985. This level resulted in a groundwater elevation of 20 feet above msl about one-half mile north of Highway 101.

Spring 1995 Groundwater Elevation Contours. Plate 14 shows spring 1995 groundwater elevation contours. The contours generally indicate conditions and directions of groundwater movement similar to those in the previous years, except for the enlargement of the depression in the south-central part of Nipomo Mesa. In the Willow Road area, groundwater elevations were below msl. The depression locally altered the direction of flow for a large portion of Nipomo Mesa and Santa Maria Valley. The direction of flow and hydraulic gradients indicate that groundwater from Santa Maria Valley (only within San Luis Obispo County) was moving into the mesa. Cleath & Associates (1996a, p. 18) also reported the existence of the depression.

Groundwater in Santa Maria Valley near the county line flowed in a westerly direction, unaffected by the depression. Because of the time lag for the recharge mound from the Santa Maria River to travel away from the river, groundwater elevations at a distance from the river did not yet reflect recharge from the 1995 wet year (almost double the long-term mean precipitation).

Several points need to be mentioned about the depression in the south-central part of Nipomo Mesa shown in Plate 14. The magnitude of the depression is not well defined because wells with groundwater level data are limited (more thorough coverage of groundwater level monitoring is needed in this part of Nipomo Mesa[12]) and reference elevations for all the wells were not surveyed. The dynamics of the groundwater system (transmitting properties of the aquifers and potential boundary conditions, such as the Santa Maria River fault) in this part of the basin likely affect development of pumping depressions. Depressions have been documented on the mesa since 1965 (California Department of Water Resources, 1979). In addition, pumpage is concentrated in this part of the mesa. Nipomo Community Services District and Southern California Water Company have many of their wells in or near the depression. The extractions of these two agencies about tripled from 1979 to 1995, from about 940 to 2,790 AF.

[12]It is beyond the scope of this study to select specific wells to be monitored.

Furthermore, the lateral extent of the depression will fluctuate depending on hydrologic conditions, amount of groundwater extractions in the area, and dynamics of the groundwater system, as the basin continuously seeks a new equilibrium. Subsurface flow from Santa Maria Valley into Nipomo Mesa will occur whenever groundwater elevations beneath the mesa are below those of the valley, altering the hydraulic gradient and direction of flow. Because of the 1998 wet year, the extent of the depression was reduced as levels in some wells rose and even continued rising in 1999 (discussed in the next section; also, see Plate A1 in the addendum).

Groundwater elevations in spring 1995 indicate that coastal groundwater elevations appeared to be above msl and outflow to the ocean was occurring. It is conjectural whether, in the future, sea water intrusion will threaten because of the pumping depressions in Nipomo Mesa. Sea water will intrude when the freshwater head is insufficient to counterbalance the greater density of sea water, even when the freshwater head is above msl.

Water Level Fluctuations and Trends

Groundwater levels in wells fluctuate over time representing the continuous adjustment of groundwater in storage to changes in recharge and discharge. The many processes that cause levels to fluctuate include pumpage, recharge from direct precipitation and streamflow, infiltration of applied water, and subsurface inflows and outflows. Hydrographs plotted from periodic water level measurements illustrate the nature of the fluctuations, both annual and long term. Observed trends in water levels are one of the most reliable means of evaluating the status of a groundwater basin.

For this study, hydrographs of water levels in selected wells were constructed and net changes in their groundwater levels were determined over time. The wells were selected on the basis of length of record, completeness of record, and geographic distribution. Wells discussed in this report are identified by their State Well Numbers.

Historical annual spring static water level measurements through water year 2000[13] were used (levels are usually highest in the spring). Some wells in Santa Maria Valley, within San Luis Obispo County, have spring groundwater level measurement records for more than 60 years, 1938 through 2000. Other wells in the basin have records for about 40 years (1959 through 2000) to shorter lengths of time (1985 through 2000). The water level measurements were converted to elevations using the reference point elevation for the well.

The water level data used in the hydrographs excluded measurements taken at pumping wells, at recently pumped wells, or at wells near pumping wells or near recently pumped wells when this information was provided in the data record. Some measurements are likely suspect because of

[13]The analysis of trends in groundwater elevations was revised from the draft report to include period of record through water year 1998 (wettest year on record), and again revised to period of record through water year 2000 at the request of San Luis Obispo County in April 2001.

errors made during the measuring process or database entry process. Gaps are found in the data. The frequency of measurement varied between the wells and over time at a given well.

Because rainfall serves as an index of available recharge for groundwater, the cumulative departure from the long-term average rainfall is also plotted on the hydrographs. Rainfall varies from year to year, tending to recur in discernible cycles of a period of relatively wet years followed by a period of several relatively dry years. These cycles are shown by the curve of cumulative departure from the long-term average rainfall. Positively sloping lines on the cumulative departure curve indicate wet years or wet periods and negatively sloping lines indicate dry years or dry periods.

Three precipitation stations with long-term records were used for different parts of the groundwater basin. The Bates Plumbing station in Arroyo Grande, with precipitation records from 1956 to 2000, was used with wells in Tri-Cities Mesa - Arroyo Grande Plain and Arroyo Grande Valley Subbasin; Nipomo 2NW station, with precipitation records from 1921 to 2000, was used with wells in Nipomo Mesa, Los Berros Creek, and Nipomo Valley Subbasin; and Santa Maria station, with precipitation records from 1886 to 2000, was used with wells in Santa Maria Valley. Since the 1930s (when the earliest water level measurements were made in the study area), there have been three wet periods of above average precipitation: water years 1937 through 1944, 1978 through 1983, and 1992 through 1998; and two dry periods of below average precipitation: water years 1945 through 1977 and 1984 through 1991. The long dry period of 1945 through 1977 is punctuated with a few wet years (1952, 1958, and 1969) and the dry period of 1984 through 1991 is punctuated with the 1986 wet year.

The behavior of the groundwater levels in the selected wells is compared to the rainfall trends and to other factors as appropriate. Although no precise correlation between groundwater elevations and rainfall exists, the graphs should generally show elevations rising during times of excess recharge and elevations declining during times of below average recharge. When precipitation and other sources of recharge are inadequate to compensate for discharges over the long term, water levels may show an overall decline over time.

The amplitude of groundwater elevation fluctuation at a particular point resulting from a given volume of recharge to or discharge from the basin is determined by the dynamics of the groundwater system (transmitting properties of the aquifers and potential boundary conditions) in the zone of fluctuation at that point. This may account for some of the differences in the degree of fluctuations on the hydrographs shown in the following figures. These differences could also be caused, in part, by uneven distribution of precipitation in the area, local differences in the infiltration rate, location of wells with respect to areas of natural discharge, use of the well, and depth to the water table below land surface.

The hydrographs in this report are grouped by the divisions of the main basin, with Nipomo Mesa subdivided into four parts-- northern, central, western, and southeastern. Hydrographs are also presented for Arroyo Grande Valley and Nipomo Valley Subbasins, but groundwater level

monitoring data are not available to prepare any hydrographs for the Pismo Creek Valley Subbasin. A summary of net changes in water levels during each of the periods of above and below average precipitation is also given on each figure.

Tri-Cities Mesa - Arroyo Grande Plain. Hydrographs of wells in Tri-Cities Mesa - Arroyo Grande Plain are shown on Figures 12 and 13. Figure 12 includes well 32S/13E-29J02, perforated in the Paso Robles Formation and wells 32S/13E-31H07 and 32S/13E-33K03, perforated in the alluvium. Figure 13 illustrates hydrographs of deeper wells, 32S/13E-29E07, 32S/13E-29G15, and 32S/13E-32D11, perforated in the Squire Member of the Pismo Formation.

On Figure 12, the hydrographs for wells 29J02 and 33K03 closely follow the rainfall trends. Well 31H07 is nearer to Arroyo Grande Creek and the response of groundwater elevations to changes in rainfall is subdued. Levels could be influenced by the location of the well near the creek, its use, its shallower depth to water (5 to 12 feet), or different characteristics of the aquifer in this part of the basin. Levels in these wells declined during the dry cycles and rose during the wet cycles. The highest water level of record for wells 29J02 and 33K03 occurred in the wet year 1983 and for well 31H07 in the wet year 1998. The figure also shows that over the long term, levels have generally been stable.

Groundwater level fluctuations in the deeper wells shown in Figure 13 do not follow rainfall trends as closely as the shallower wells in Figure 12. Lack of measurements in some years affects the apparent pattern of fluctuations. The aquifer properties of these deeper wells are different, affecting their response to recharge and discharge events. Also wells 29E07 and 29G15 show almost no annual variability since the early 1990s, suggesting changed well use such as increased production. During the dry cycle of 1984 to 1991, wells 29E07 and 29G15 had levels that dropped below msl and well 32D11 dropped to a foot above msl. Levels recovered during the following wet cycle. All three wells show a decline in levels over their period of record, between about 4 and 11 feet, an indication that discharge may be exceeding recharge of the Squire Member aquifers in this part of the basin.

Los Berros Creek. Figure 14 presents hydrographs of wells 12N/35W-34C03 and 12N/35W-35K02, perforated in the alluvial aquifer of Los Berros Creek. Groundwater levels in the wells generally follow rainfall trends. The lowest water levels in these wells occurred in the dry year 1990. Well 34C03 had a net rise in levels of about four feet over its period of record and well 35K02, about seven feet. Based on the long-term trends in levels in these wells, it appears that recharge and discharge are generally in balance over time in this part of the basin.

Northern Nipomo Mesa. Figure 15 presents hydrographs of wells perforated in the Paso Robles Formation. Wells 12N/35W-32G01 and 12N/35W-33L01 are on the south side of the Santa Maria River fault. Wells 12N/35W-33E01, 11N/35W-03B01, and 11N/35W-02G02 are on the north side of the Santa Maria River fault. The figure clearly shows the large differences in groundwater elevations found on opposing sides of the fault, about 90 to 125 feet of difference.

FIGURE 12 - TREND IN GROUNDWATER ELEVATIONS, TRI-CITIES MESA - ARROYO GRANDE PLAIN SHALLOW WELLS

NET RISES AND DECLINES IN GROUNDWATER LEVELS

State Well No.	Periods of Above and Below Average Rainfall [a]1945-77	1978-83	1984-91	1992-98	Record through 1998	Record through 2000
32S/13E-29J02	-8.3	3.2	-16.4	7.1	1.5	-3.2
32S/13E-31H07	0.1	1.0	-1.8	4.1	5.0	2.8[1965-99]
32S/13E-33K03	-18.0	6.2	-1.8	8.4	5.0	-3.6

[a] Refer to hydrograph for beginning of record for well.

Note: Cumulative Departure is based on the long-term average rainfall, 1956-2000, at the Bates Plumbing station in Arroyo Grande.

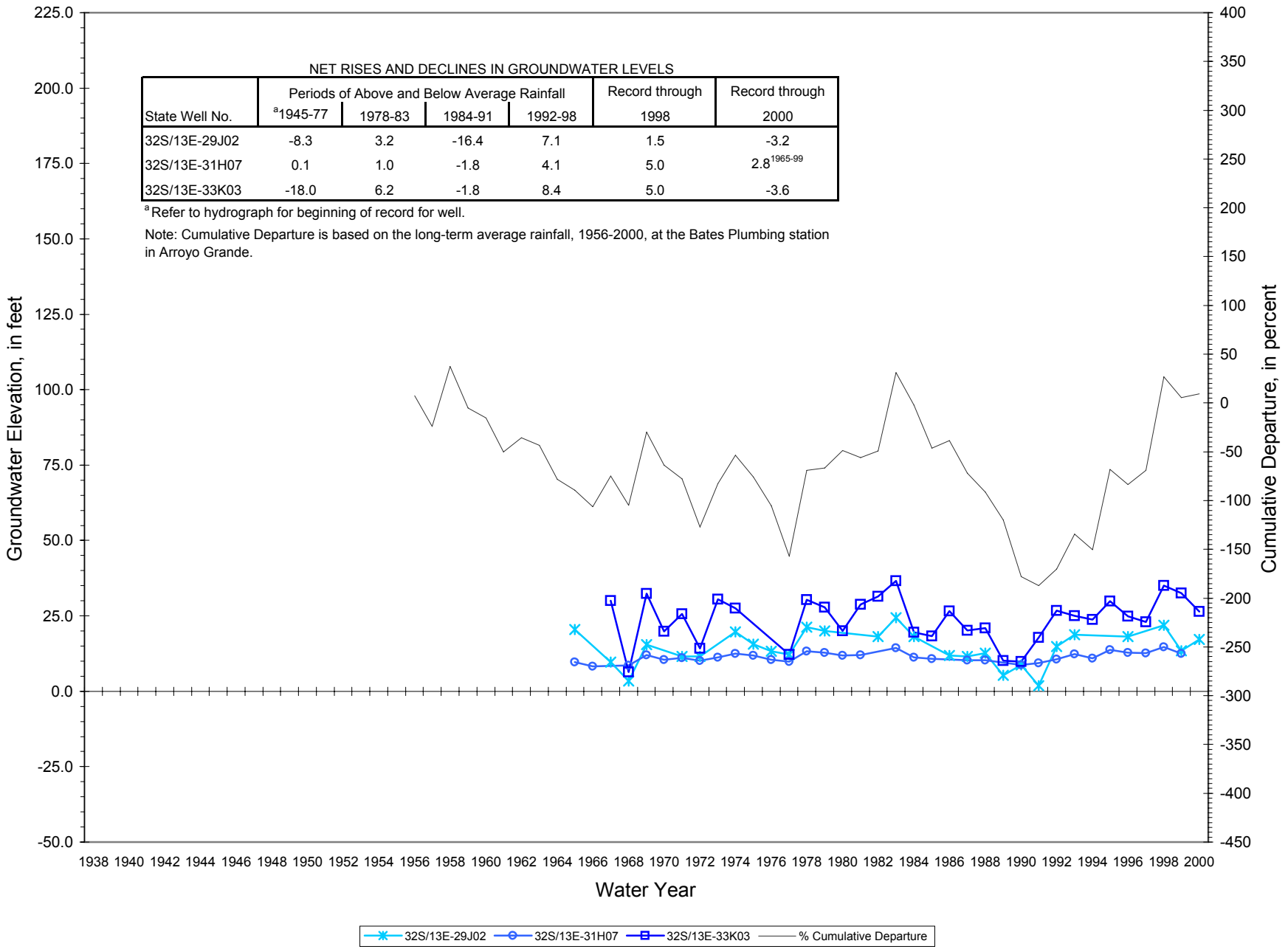


FIGURE 13 - TREND IN GROUNDWATER ELEVATIONS, TRI-CITIES MESA - ARROYO GRANDE PLAIN DEEP WELLS

NET RISES AND DECLINES IN GROUNDWATER LEVELS

State Well No.	Periods of Above and Below Average Rainfall 1978-83[a]	1984-91	1992-98	Record through 1998	Record through 2000
32S/13E-29E07	3.3	-10.3[1986-91]	2.0[1992-97]	-3.8[1979-97]	-3.8[1979-99]
32S/13E-29G15		-5.5	[b]	-10.4[1983-97]	-11.1
32S/13E-32D11	8.6	-7.9	5.8	4.0	-4.2

[a] Refer to hydrograph for beginning of record for well.

[b] Well only measured in 1997.

Note: Cumulative Departure is based on the long-term average rainfall, 1956-2000, at the Bates Plumbing station in Arroyo Grande.

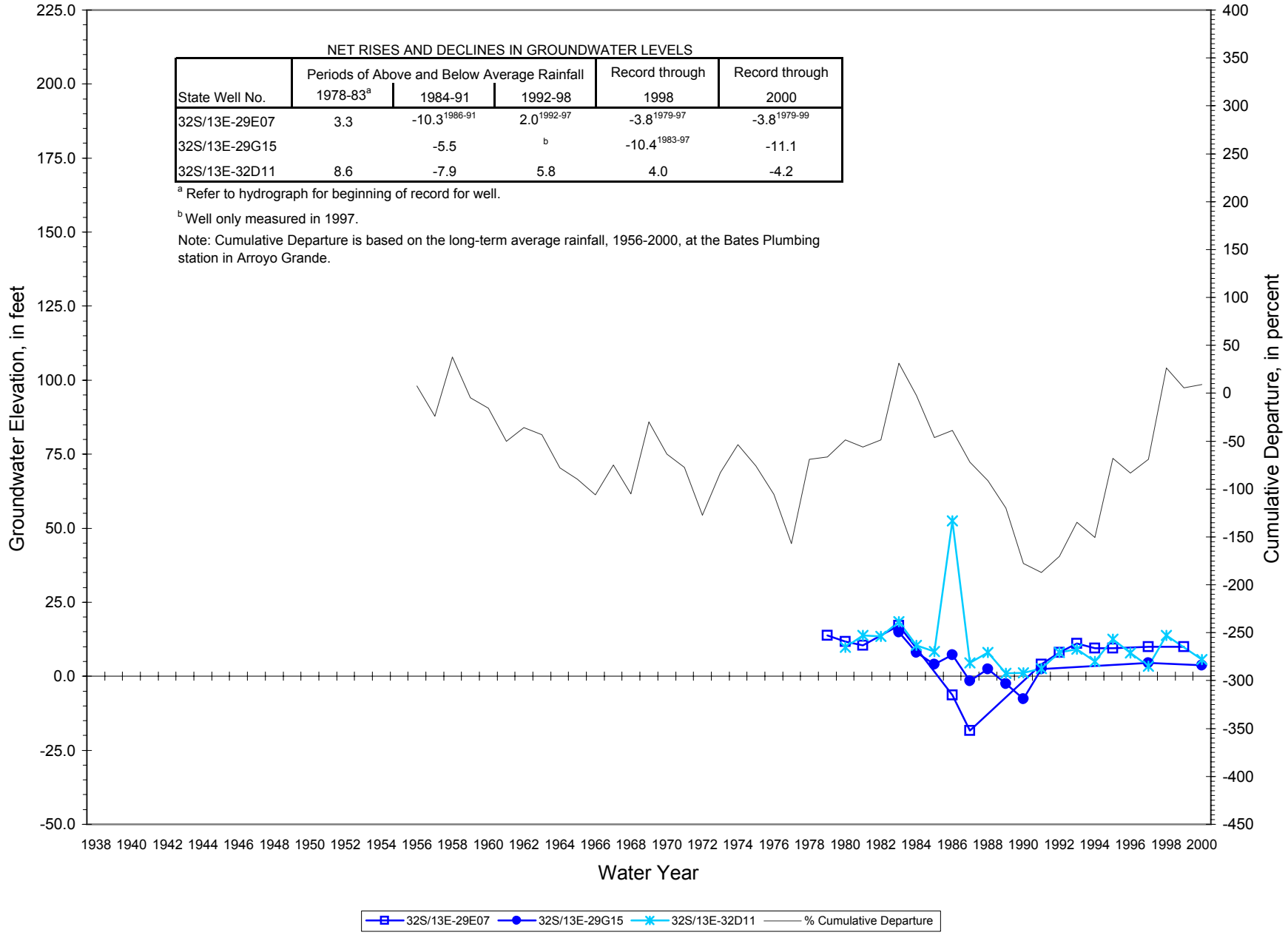
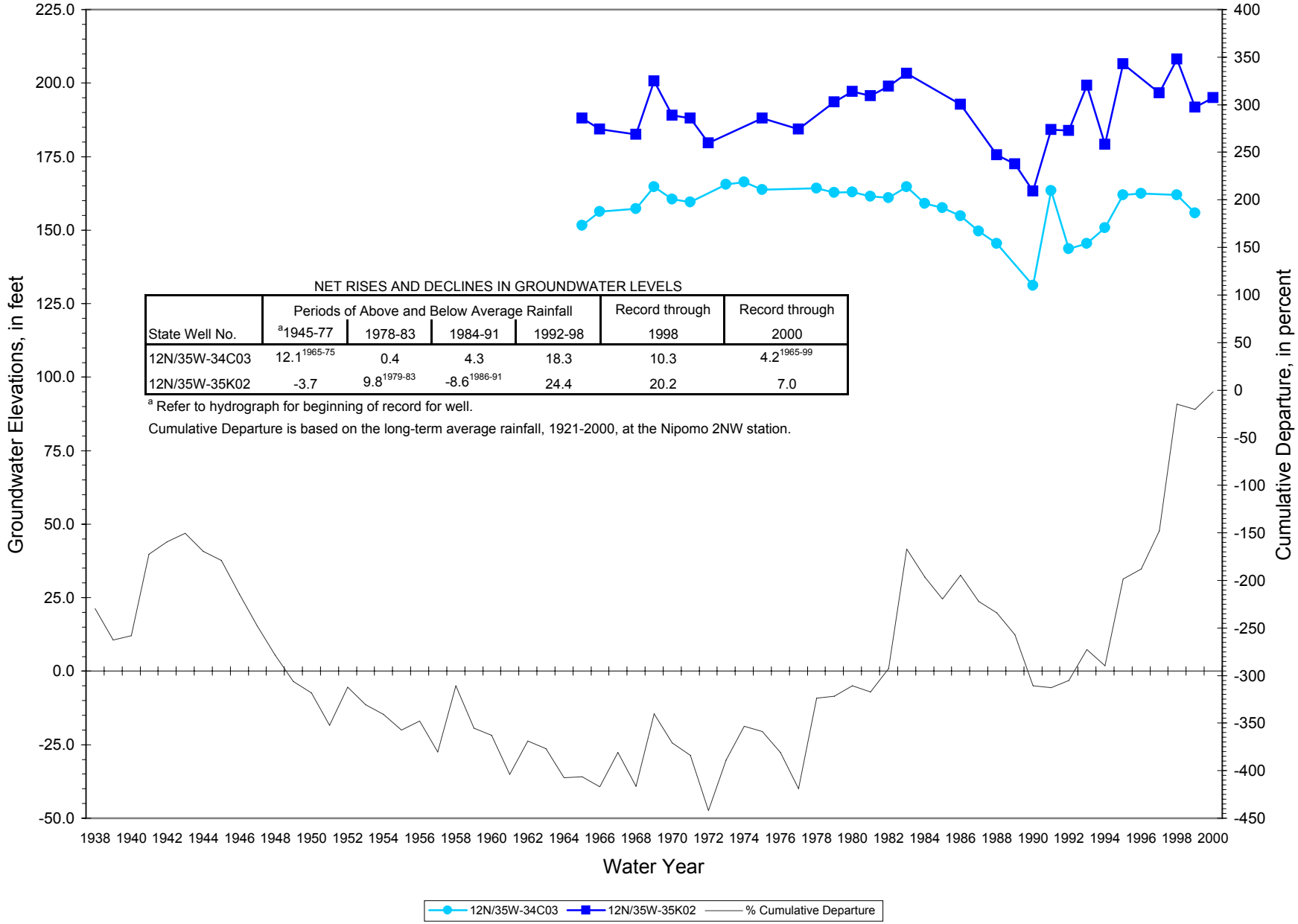


FIGURE 14 - TREND IN GROUNDWATER ELEVATIONS, LOS BERROS CREEK WELLS



NET RISES AND DECLINES IN GROUNDWATER LEVELS

State Well No.	Periods of Above and Below Average Rainfall [a]1945-77	1978-83	1984-91	1992-98	Record through 1998	Record through 2000
12N/35W-34C03	12.1 (1965-75)	0.4	4.3	18.3	10.3	4.2 (1965-99)
12N/35W-35K02	-3.7	9.8 (1979-83)	-8.6 (1986-91)	24.4	20.2	7.0

[a] Refer to hydrograph for beginning of record for well.

Cumulative Departure is based on the long-term average rainfall, 1921-2000, at the Nipomo 2NW station.

FIGURE 15 - TREND IN GROUNDWATER ELEVATIONS, NORTHERN NIPOMO MESA WELLS

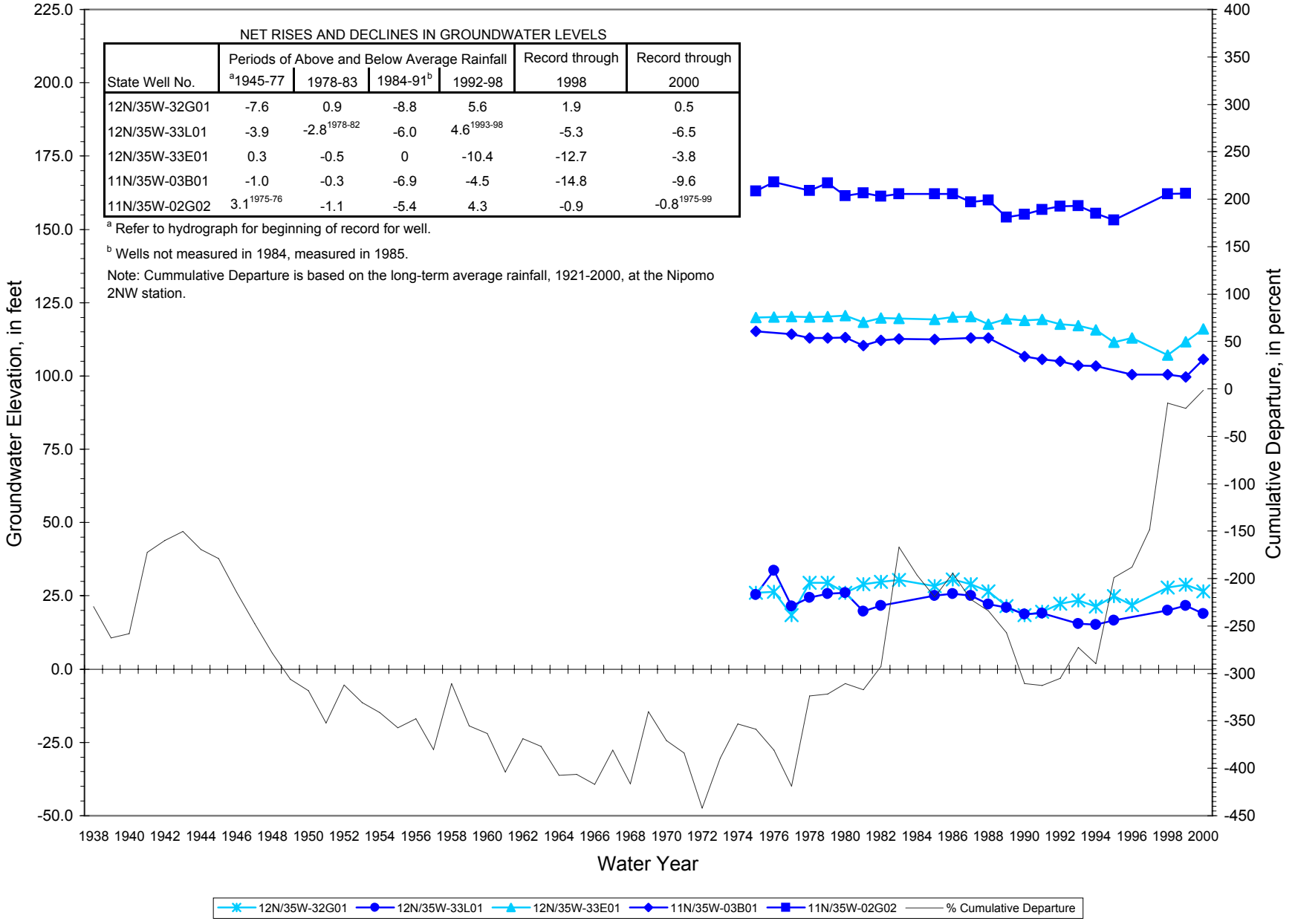
NET RISES AND DECLINES IN GROUNDWATER LEVELS

State Well No.	Periods of Above and Below Average Rainfall				Record through	Record through
	[a]1945-77	1978-83	1984-91[b]	1992-98	1998	2000
12N/35W-32G01	-7.6	0.9	-8.8	5.6	1.9	0.5
12N/35W-33L01	-3.9	-2.8 1978-82	-6.0	4.6 1993-98	-5.3	-6.5
12N/35W-33E01	0.3	-0.5	0	-10.4	-12.7	-3.8
11N/35W-03B01	-1.0	-0.3	-6.9	-4.5	-14.8	-9.6
11N/35W-02G02	3.1 1975-76	-1.1	-5.4	4.3	-0.9	-0.8 1975-99

[a] Refer to hydrograph for beginning of record for well.

[b] Wells not measured in 1984, measured in 1985.

Note: Cummulative Departure is based on the long-term average rainfall, 1921-2000, at the Nipomo 2NW station.



Levels in wells on the north side of the Santa Maria River fault, 33E01, 03B01, and 02G02, show almost no variability and no correlation with trends in rainfall. The levels in these wells have steadily declined over time, despite cycles of greater rainfall. Well 33E01 had a record low level in 1998, the wettest rainfall year on record. Over the period of record, the decline ranged from about 10 feet in well 03B01 to about one foot in well 02G02.

Wells 32G01 and 33L01 on the south side of the fault show a subdued correlation to trends in rainfall. Groundwater levels in well 33L01 declined about six feet over its period of record. This well is within the depression by Halcyon Road shown on Plate14. Levels in well 32G01 had a net rise of a half-foot over its period of record, an amount that may be attributable to water level measuring practices.

In northern Nipomo Mesa, wells on both sides of the Santa Maria River fault are showing small long-term declines in water levels. In this part of the basin, the volume of groundwater withdrawn for use may be slightly exceeding recharge, resulting in small declines in the amount of groundwater in storage.

Central Nipomo Mesa. Hydrographs of four wells perforated in the Paso Robles Formation are shown on Figure 16. Wells 11N/35W-02N01, 11N/35W-10G01, and 11N/35W-11J01 are on the south side of the Santa Maria River fault and well 11N/35W-11C01 is on the north side of the fault. As mentioned earlier, groundwater elevations are similar on opposite sides of the fault along the segment near the head of Black Lake Canyon (north of Willow Road to about a mile east of Zenon Way).

Well 02N01 is near the head of Black Lake Canyon and at the edge of the depression shown on Plate 14. The levels in this well do not follow rainfall trends, showing no response to wet years. The levels have declined almost steadily over time, about one foot per year over the period of record. Monitoring of this well stopped in 1996.

Well 10G01 is in the center of the depression shown on Plate 14. Prior to 1985, this well had been used for irrigation, and measurements of water levels were sporadic. In 1985, the pump was removed, contributing to the rise in levels in 1986. The well is now used for observation only. The fluctuations of levels in this well may be affected by the extractions of nearby wells. The greatest rise in levels in response to recharge from rainfall occurred in the wet year 1969, when the groundwater level rose 65 feet. Levels declined 72 feet between 1969 and 1978, dropping below msl. Between 1986 and 1991, levels declined about 50 feet, but recovered and rose about 12 feet by 2000. The spring levels have been continuously below msl since 1987. The average decline over the period of record is about 0.13 foot per year.

Groundwater levels in well 11J01 do not show a correlation with rainfall. Levels rose about three feet over its period of record, even rising during the dry period 1984 through 1991, when rainfall was 32 percent below normal. The use of this well may have changed around 1985. Prior to 1985, the well was used for stock and irrigation. Since that time, the well appears to be

FIGURE 16 - TREND IN GROUNDWATER ELEVATIONS, CENTRAL NIPOMO MESA WELLS

NET RISES AND DECLINES IN GROUNDWATER LEVELS

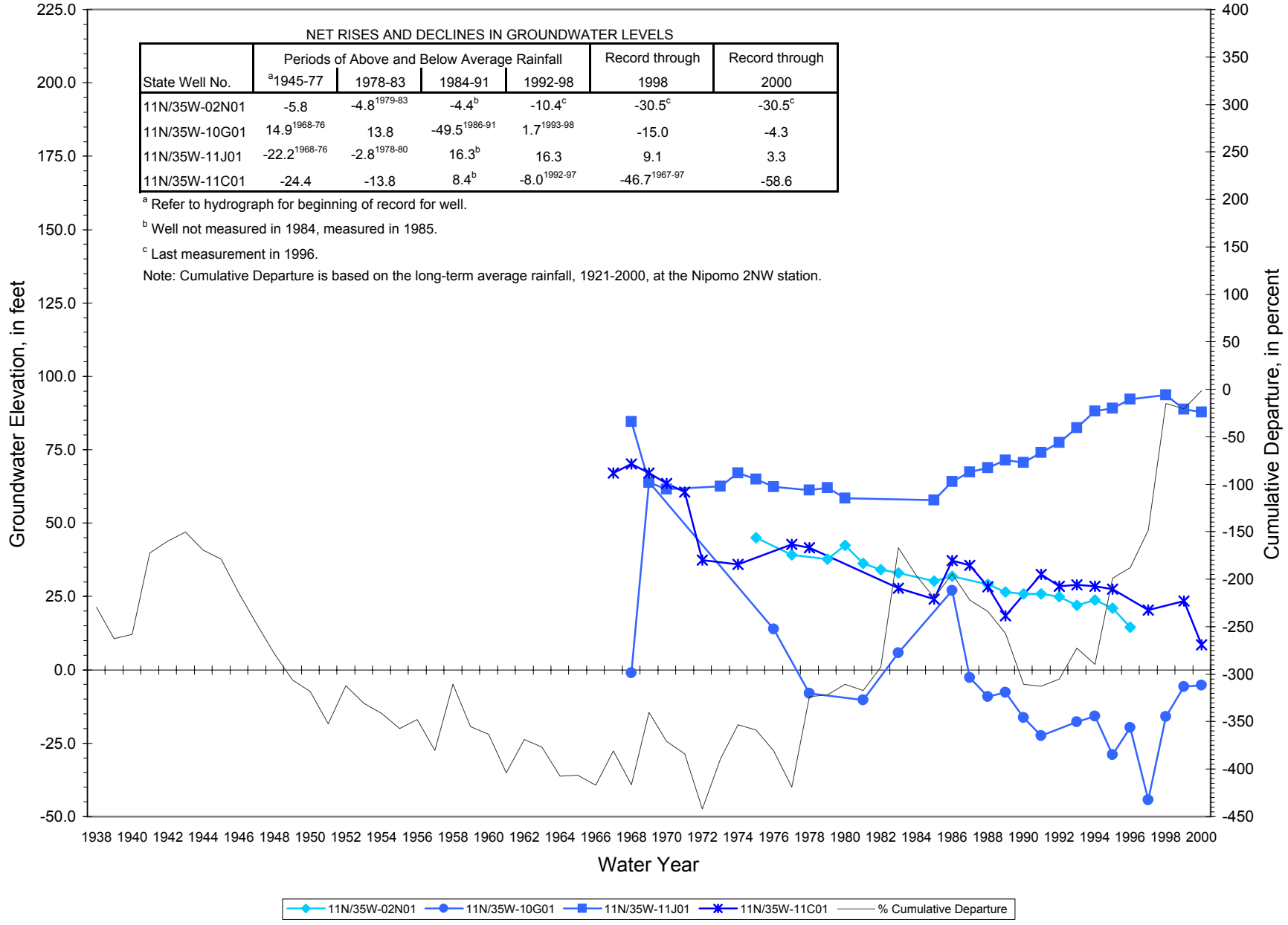
State Well No.	Periods of Above and Below Average Rainfall				Record through 1998	Record through 2000
	[a]1945-77	1978-83	1984-91	1992-98		
11N/35W-02N01	-5.8	-4.8 [1979-83]	-4.4[b]	-10.4[c]	-30.5[c]	-30.5[c]
11N/35W-10G01	14.9 [1968-76]	13.8	-49.5 [1986-91]	1.7 [1993-98]	-15.0	-4.3
11N/35W-11J01	-22.2 [1968-76]	-2.8 [1978-80]	16.3[b]	16.3	9.1	3.3
11N/35W-11C01	-24.4	-13.8	8.4[b]	-8.0 [1992-97]	-46.7 [1967-97]	-58.6

[a] Refer to hydrograph for beginning of record for well.

[b] Well not measured in 1984, measured in 1985.

[c] Last measurement in 1996.

Note: Cumulative Departure is based on the long-term average rainfall, 1921-2000, at the Nipomo 2NW station.



used just for domestic water and groundwater levels have steadily risen. This well is unaffected by the depression shown on Plate 14. Also, a nearby well had levels that rose 37 feet between 1988 and 1996. Wells with level measurements in the immediate area, just south of the Santa Maria River fault, indicate a balance between recharge and discharge.

Well 11C01, located on the north side of Santa Maria River fault and near the head of Black Lake Canyon, is monitored but not in use. The groundwater levels dropped too low and the well sanded up. In 1972, the water level in this well declined 23 feet in a year in which precipitation was about 40 percent of normal. Fluctuations of levels in this well do not appear to correlate well with rainfall, some years with high rainfall do not result in a corresponding rise in groundwater levels. Levels have declined almost 60 feet over the period of record; however, the initial groundwater level measurements may have been perched levels, which are common near the head of the canyon.

In wells such as 02N01, 10G01, and 11C01, the long-term declines in groundwater levels reflect a lack of balance between recharge and discharge and the loss of groundwater storage that is occurring in this part of the mesa.

Western Nipomo Mesa. The wells with hydrographs shown on Figure 17 are located south of the Oceano fault. Well 11N/35W-05L01 is on the north side of Black Lake Canyon and well 11N/35W-05R01 is on the south side of the canyon. Both wells are perforated in the Paso Robles Formation. Well 11N/35W-09K04 is south of Willow Road and east of Highway 1. A well completion report is not available for this well, but it is also likely perforated in the Paso Robles Formation.

The hydrographs show that water levels in these wells vary from year to year generally in close correlation with trends in rainfall. The greater variability of levels in well 09K04 may be attributable to its use, the presence of other wells nearby, applied water use in the area, variability in rainfall distribution, or differences in hydraulic properties of the water-bearing sediments.

Wells 05L01 and 05R01 are at the edge of a small depression near the lower end of Black Lake Canyon, shown on Plate 14. The hydrographs of these wells show that over the long term, levels have generally been stable, with a small decline of about one foot over their periods of record. That amount of decline may be attributable to water level measuring practices and it appears recharge is balancing discharge over time.

Southeastern Nipomo Mesa. Figure 18 presents hydrographs of wells located in southeastern Nipomo Mesa. Wells 11N/34W-19Q01, 11N/35W-13E02, 11N/35W-24D01, and 11N/35W-24L02 are perforated in the Paso Robles Formation and are located between the Oceano fault and the Santa Maria River fault. Well 11N/34W-27E01 is perforated in the Squire Member of the Pismo Formation and is located between the Santa Maria River fault and the Wilmar Avenue fault, at the edge of the boundary for Nipomo Mesa HSA.

FIGURE 17 - TREND IN GROUNDWATER ELEVATIONS, WESTERN NIPOMO MESA WELLS

NET RISES AND DECLINES IN GROUNDWATER LEVELS

State Well No.	Periods of Above and Below Average Rainfall				Record through	Record through
	[a]1945-77	1978-83	1984-91	1992-98	1998	2000
11N/35W-05L01	-13.4	12.3	-1.3	11.1	0.9	-0.6
11N/35W-05R01	-14.4	5.1	-5.3[b]	-4.3[1992-97]	-13.1[1975-97]	-1.1
11N/35W-09K04	-16.1	-2.8	23.6[b]	19.3	2.4	-0.3

[a] Refer to hydrograph for beginning of record for well.

[b] Well not measured in 1984, measured in 1985.

Note: Cumulative Departure is based on the long-term average rainfall, 1921-2000, at the Nipomo 2NW station.

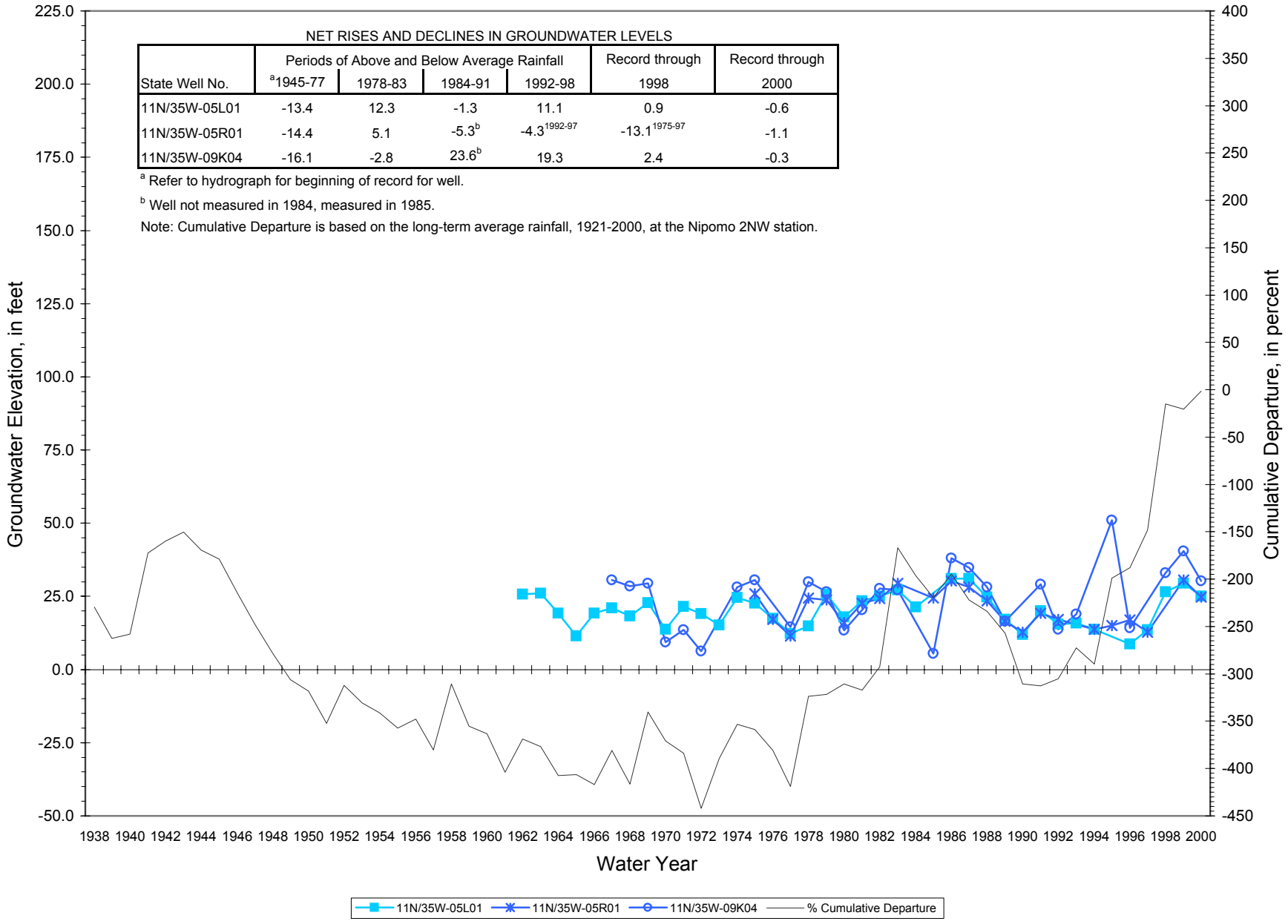


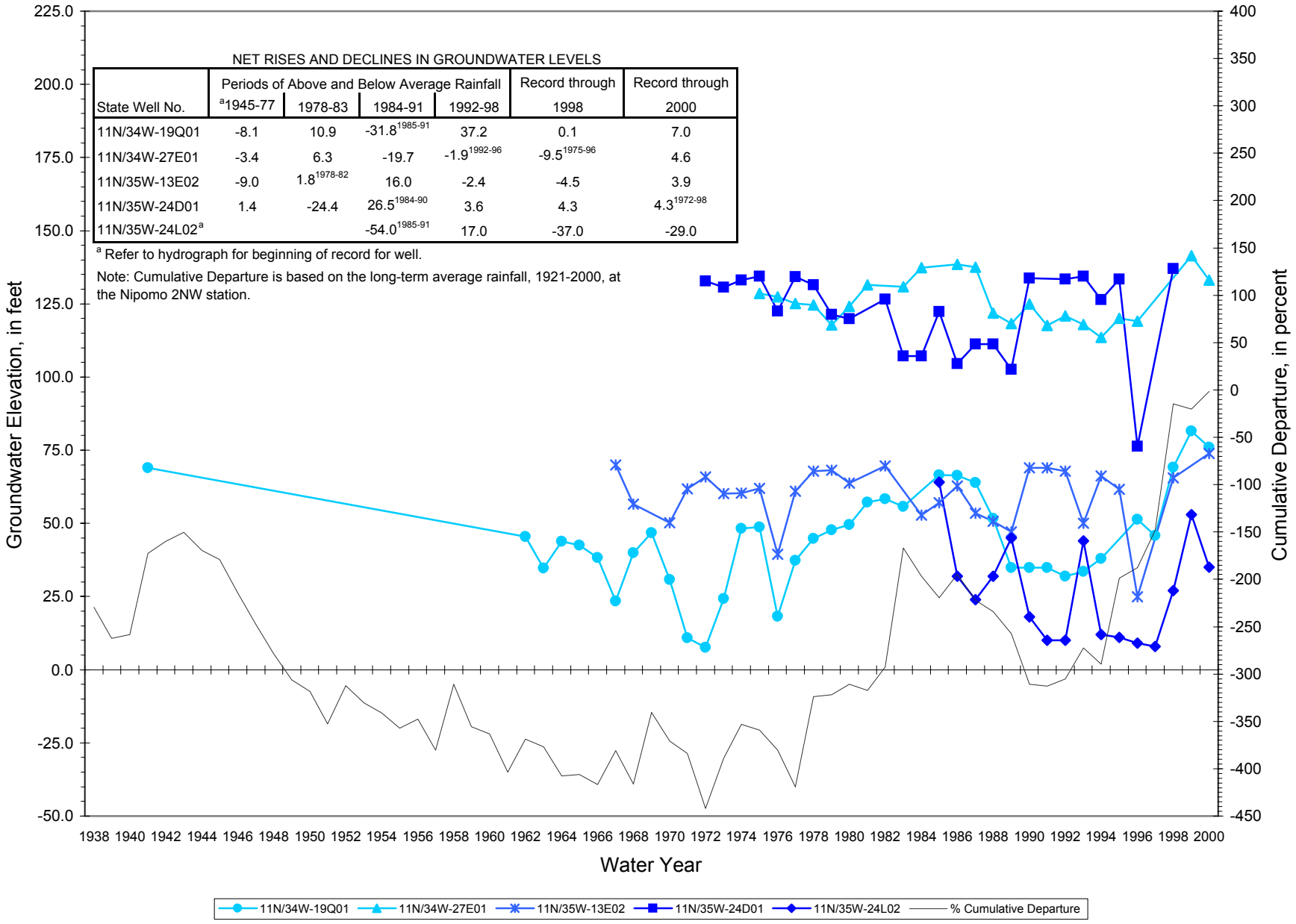
FIGURE 18 - TREND IN GROUNDWATER ELEVATIONS, SOUTHEASTERN NIPOMO MESA WELLS

NET RISES AND DECLINES IN GROUNDWATER LEVELS

State Well No.	Periods of Above and Below Average Rainfall				Record through 1998	Record through 2000
	[a]1945-77	1978-83	1984-91	1992-98		
11N/34W-19Q01	-8.1	10.9	-31.8[1985-91]	37.2	0.1	7.0
11N/34W-27E01	-3.4	6.3	-19.7	-1.9[1992-96]	-9.5[1975-96]	4.6
11N/35W-13E02	-9.0	1.8[1978-82]	16.0	-2.4	-4.5	3.9
11N/35W-24D01	1.4	-24.4	26.5[1984-90]	3.6	4.3	4.3[1972-98]
11N/35W-24L02[a]			-54.0[1985-91]	17.0	-37.0	-29.0

[a] Refer to hydrograph for beginning of record for well.

Note: Cumulative Departure is based on the long-term average rainfall, 1921-2000, at the Nipomo 2NW station.



Fluctuations in groundwater levels in well 19Q01 generally follow trends in rainfall. The static water level reported on the well completion report at the time the well was drilled in 1941 is included on the hydrograph. Since 1998, water levels have been higher than the 1941 level. The water level rose 23 feet in the 1998 wet year and continued to rise another 12.5 feet in 1999. Although this well is on the mesa, it is about 2 miles northwest of the Santa Maria River and may also be recharged from infiltration from the river.

Water level fluctuations in well 13E02 do not generally follow rainfall trends. A net rise in water levels occurred in the dry period of 1984 through 1991 and a small net decline in water levels occurred in the wet period of 1992 through 1998. Other factors may be influencing the levels in this well, such as the use of the well, the presence of other wells nearby, applied water use in the area, variability in rainfall distribution, or differences in hydraulic properties of the water-bearing sediments. Over its period of record, levels in this well rose about four feet.

Groundwater elevations in well 24D01 represent perched water conditions. The well is within the depression shown on Plate 14, but its water levels are not being affected as are levels of the principal groundwater body. Well 24D01 had a net rise of about four feet in levels over its period of record. Fluctuations in water levels in this well do not correlate with rainfall. This well had a net decline in water levels during the wet period of 1978 through 1983 and a net rise in water levels during the dry period of 1984 through 1991. The low groundwater elevation in 1996 may not be a static level, but no comment was noted in the county's database.

Well 24L02, a water agency production well, is within the depression shown on Plate 14 and levels are being affected by extractions that exceed recharge in this area. Water level response to wet years is affected by production from the well. Over its period of record (1985 to 2000), water levels have declined about 30 feet, or about two feet per year.

Groundwater elevations in well 27E01 are not perched levels, but are representative of groundwater elevations on the north side of this segment of the Santa Maria River fault. The hydrograph of this well is included on Figure 18 to illustrate the possible differences in groundwater elevations found on opposing sides of the fault along this segment. Levels in this well generally follow rainfall trends. Over its period of record, levels rose about five feet.

Summary Comments on Nipomo Mesa Groundwater Elevation Trends. Nipomo Mesa has seen increasing development along with associated increased demands on groundwater supplies (from 1975 to 1990 demand on groundwater supplies rose about 170 percent). The increased withdrawals are reflected in the declining trends in groundwater levels in some wells[14] in parts of the basin (the part between the Santa Maria River fault and the Oceano fault and the part north of the Santa Maria River fault around El Campo Road), despite periods of 40 percent above average precipitation. In those parts of the basin, concentrated pumpage, the dynamics of the

[14]Declining water levels in wells can lead to increased pumping costs, localized well interference, loss of production capacity, and possible quality degradation.

groundwater system (transmitting properties of the aquifers and potential boundary conditions, such as the Santa Maria River fault), and sources of recharge influence groundwater level trends. If declines in groundwater levels continue in the future and expand to additional parts of the basin, the groundwater resources of the basin could be threatened by sea water intrusion. The localized declines in groundwater levels reflect decreases in estimated amounts of groundwater in storage between 1975 and 1995, discussed in the next section.

However, in other parts of the basin in Nipomo Mesa, the long-term fluctuations in water levels in wells reflect hydrologic variations, following alternating periods of decline and recovery, and indicate that recharge is balancing discharge over the long term.

The eastern edge of the mesa, bounded by Summit Station Road, Hetrick Avenue, the Santa Maria River fault, Highway 101, and Joshua Road lacks water level monitoring data. Wells in this part of the basin need to be included in the county's monitoring program. It is beyond the scope of this study to select specific wells to be monitored.

Santa Maria Valley. Figure 19 presents hydrographs of three wells in Santa Maria Valley within the study area and a summary of net changes in water levels during each of the wet and dry periods. Well 11N/34W-30Q01 is perforated in the alluvium adjacent to the river channel in the eastern part of the valley. Well 11N/35W-20E01 is perforated in the Paso Robles Formation about 3.5 miles north of the river channel and about 2.5 miles inland from the coast. Well 11N/35W-28M01, perforated in the Paso Robles Formation, is in about the center of the valley approximately 2 miles north of the river channel, near Highway 1.

In Santa Maria Valley, because the water table nearly everywhere is below the channel of the Santa Maria River, there is seldom, if ever, any hydraulic connection between water in the channel and the groundwater body. Thus, levels in wells rise in response to recharge from the river, but do not fluctuate in accord with the stage of the river. Each year's recharge travels away from the river as a mound. At a distance from the river, there may be a time lag of up to about a year for water levels in wells to be affected.

The hydrographs in Figure 19 illustrate the alternating periods of water level decline and recovery and the ranges of fluctuations in water levels observed since the 1930s, when measurements began. The hydrographs also illustrate the generally clear correlation of water level fluctuations with trends in rainfall.

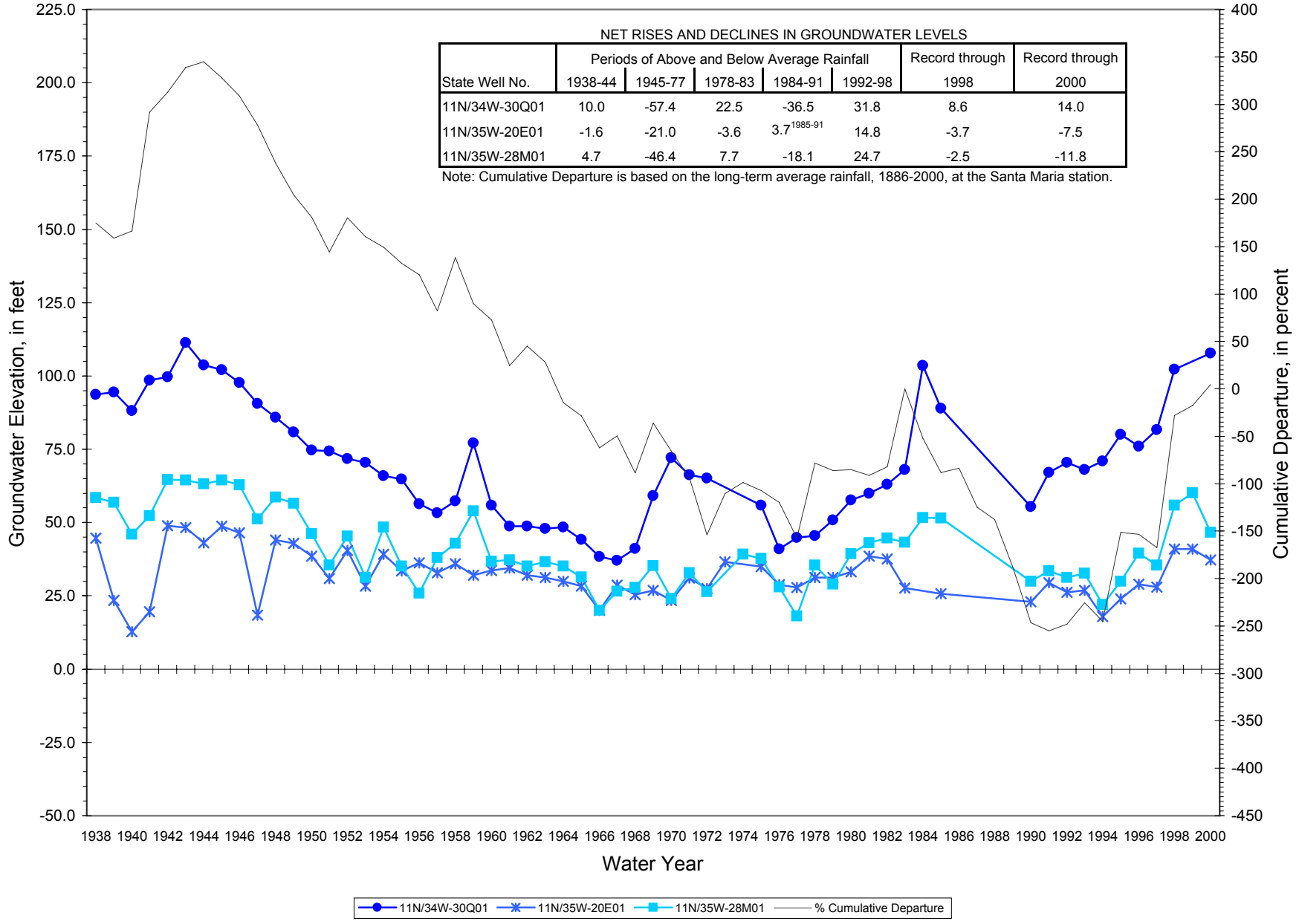
During the 1945 through 1977 dry cycle, a substantial decline in groundwater levels from the highs of the early 1940s occurred. Declines in water levels in these wells ranged from 0.6 foot per year in well 20E01 to 1.7 feet per year in well 30Q01. The net declines were the result of drier than normal climatic conditions and increased pumpage. Some recovery of groundwater levels occurred in wells 30Q01 and 28M01 during the 1978 through 1983 wet period. Levels again declined during the 1984 through 1991 dry period, with declines ranging from 1.1 to 4.5 feet per year. Levels rose during the 1992 through 1998 wet cycle, and it can be seen that by

FIGURE 19 - TREND IN GROUNDWATER ELEVATIONS, SANTA MARIA VALLEY WELLS

NET RISES AND DECLINES IN GROUNDWATER LEVELS

State Well No.	Periods of Above and Below Average Rainfall 1938-44	1945-77	1978-83	1984-91	1992-98	Record through 1998	Record through 2000
11N/34W-30Q01	10.0	-57.4	22.5	-36.5	31.8	8.6	14.0
11N/35W-20E01	-1.6	-21.0	-3.6	$3.7^{1985-91}$	14.8	-3.7	-7.5
11N/35W-28M01	4.7	-46.4	7.7	-18.1	24.7	-2.5	-11.8

Note: Cumulative Departure is based on the long-term average rainfall, 1886-2000, at the Santa Maria station.



1998 water levels had recovered to near historical highs. Between 1975 and 1995, agricultural demand on groundwater supplies declined 30 percent, contributing to the recovery of water levels in Santa Maria Valley. The long-term changes of water levels in these wells appear to reflect hydrologic variations and indicate that recharge is balancing discharge in the valley.

A diagrammatic section with water level profiles along the Santa Maria River, first constructed by Worts (1951), was updated with 1995 and 1998 levels for this study. The section is presented in Figure 20. The section shows the hydraulic gradients for the various years projected to the coastline, indicating outflow to the ocean during those years. The section also illustrates that water levels in 1998 almost returned to the high levels of 1944.

Arroyo Grande Valley Subbasin. Hydrographs of two wells located in Arroyo Grande Valley Subbasin are shown on Figure 21. Wells 32S/13E-23F01 and 32S/13E-12Q03 are perforated in alluvium. Levels in these wells show the stabilizing effect of the releases from Lopez Reservoir since 1969, particularly during dry periods. During the 1984 through 1991 dry period, both wells had net rises in levels, while wells in Tri-Cities Mesa - Arroyo Grande Plain showed net declines (Figure 12). From 1998 to 2000, the levels in these wells have dropped; well 23F01 declined 30 feet since the high elevations of 1998.

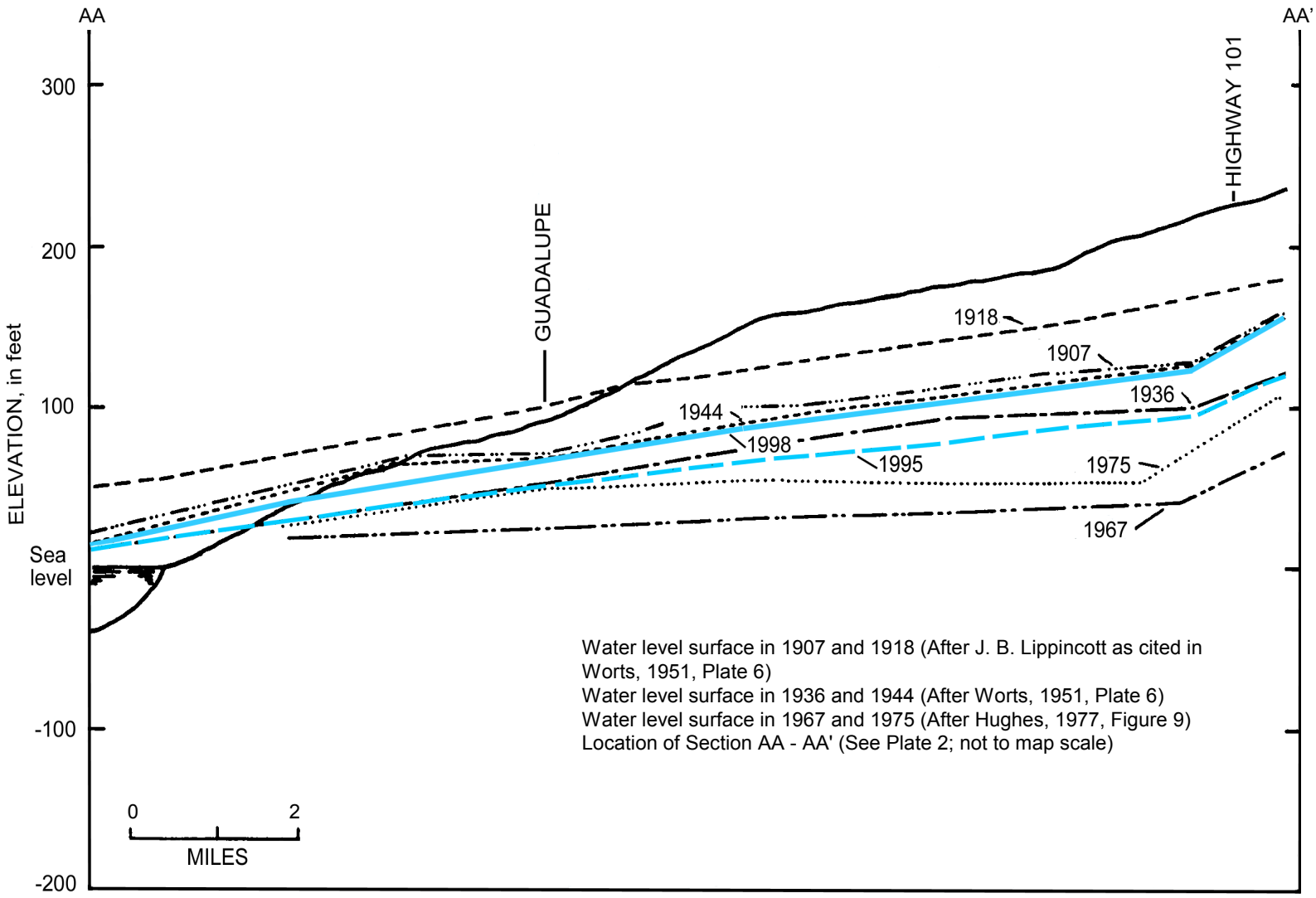
Nipomo Valley Subbasin. Figure 22 shows hydrographs of three wells perforated in the Monterey Formation, because groundwater levels in wells perforated only in the older alluvium are not monitored by the county in Nipomo Valley Subbasin. The graphs show the greater cyclic fluctuation in fractured bedrock wells than in wells perforated in unconsolidated sediments of the main groundwater basin. The wells generally show rising levels during wet periods and falling levels during dry periods. Over the period of record, wells 11N/34W-09P01 and 11N/34W-05K01 had a rise in levels, while well 11N/34W-17B04 showed a small decline of about 1.5 feet.

Summary Comments on Hydrographs. The hydrographs in Figures 12 through 22 show that long-term trends in groundwater levels, with the exception of some parts of the basin in Nipomo Mesa, reflect hydrologic variations, following alternating periods of decline and recovery, and indicate that recharge is balancing discharge over the long term. Further, it can be seen that trends are not manifested in the entire basin simultaneously because of its size and variations in sources of groundwater recharge or discharge and other mechanisms operating locally.

Groundwater Storage

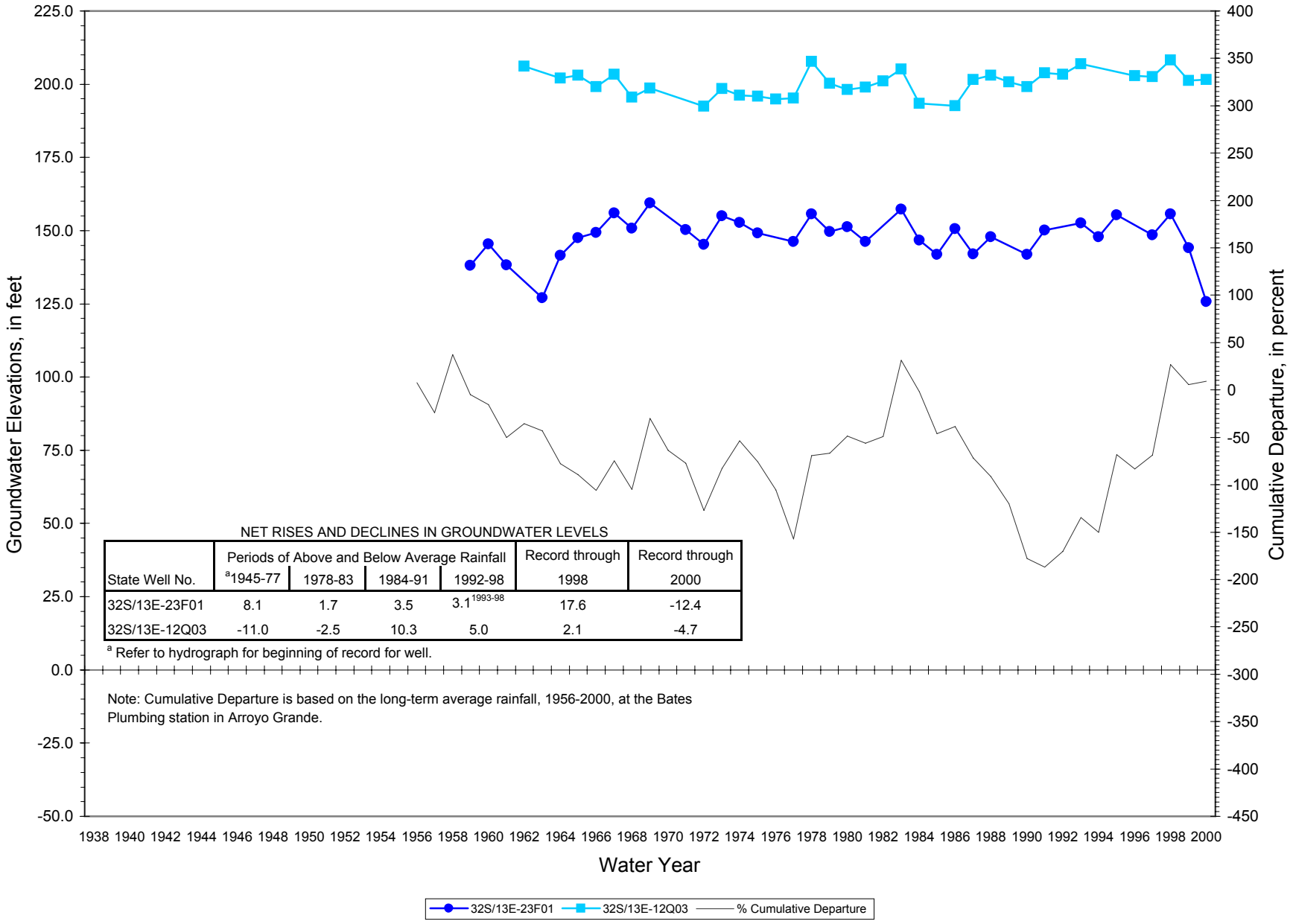
Porosity and Specific Yield. Two important hydraulic properties of an aquifer that are related to its storage function are porosity and specific yield (storativity). Porosity is the ratio of voids in a rock or sediment to the total volume of material and is an index of how much groundwater can be stored in a saturated material. Porosity is usually expressed as a percentage and can be classified as either primary or secondary. Primary porosity represents the original openings present when the sediment or rock was formed (Fetter, 1988). Secondary porosity consists of openings formed through fracturing or weathering of a rock or sediment after it was formed (Ibid.).

FIGURE 20 - DIAGRAMMATIC SECTION SHOWING GROUNDWATER LEVEL PROFILES ALONG THE SANTA MARIA RIVER



Water level surface in 1907 and 1918 (After J. B. Lippincott as cited in Worts, 1951, Plate 6)
Water level surface in 1936 and 1944 (After Worts, 1951, Plate 6)
Water level surface in 1967 and 1975 (After Hughes, 1977, Figure 9)
Location of Section AA - AA' (See Plate 2; not to map scale)

FIGURE 21 - TREND IN GROUNDWATER ELEVATIONS, ARROYO GRANDE VALLEY SUBBASIN WELLS



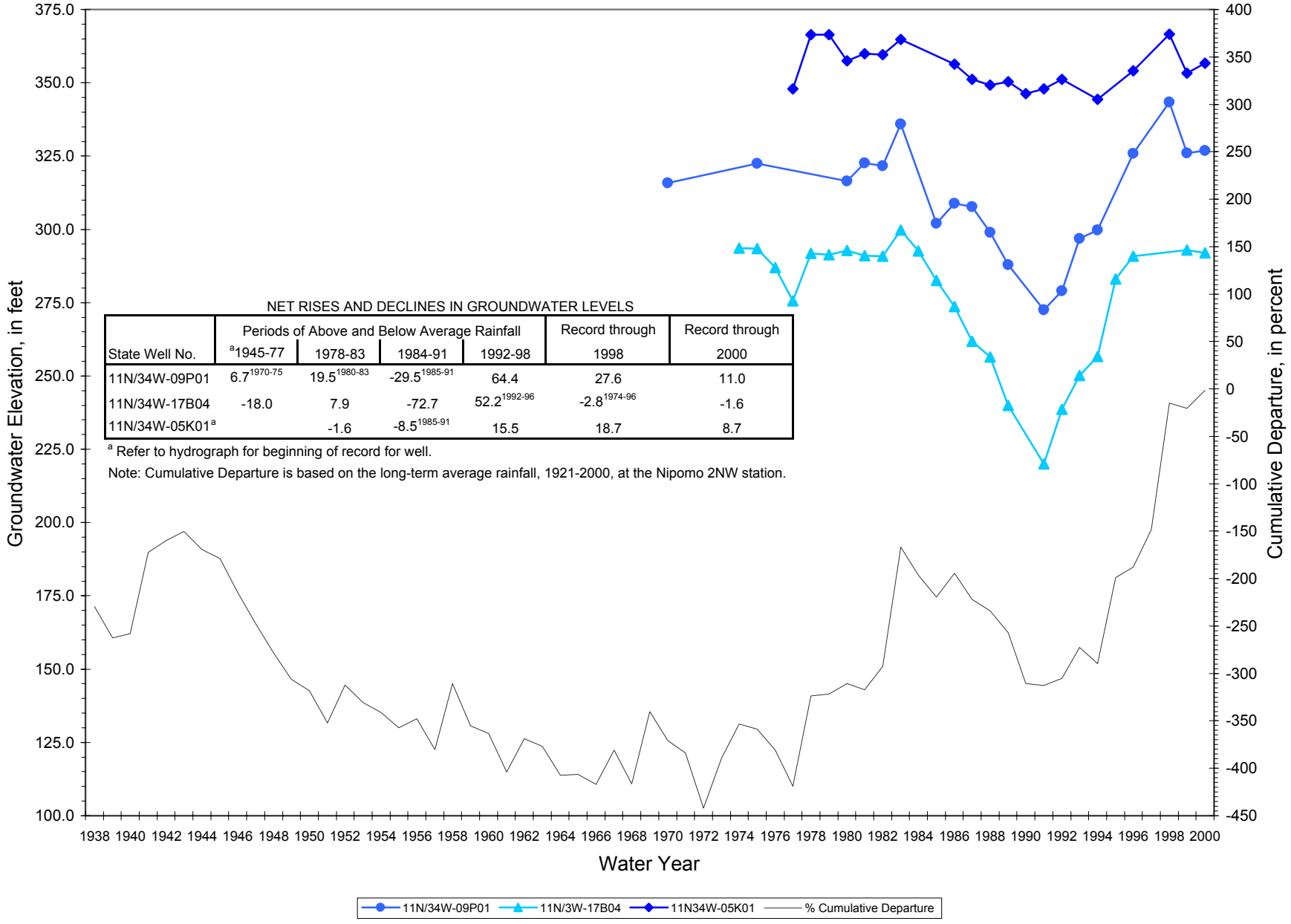
NET RISES AND DECLINES IN GROUNDWATER LEVELS

State Well No.	Periods of Above and Below Average Rainfall [a]1945-77	1978-83	1984-91	1992-98	Record through 1998	Record through 2000
32S/13E-23F01	8.1	1.7	3.5	3.1 [1993-98]	17.6	-12.4
32S/13E-12Q03	-11.0	-2.5	10.3	5.0	2.1	-4.7

[a] Refer to hydrograph for beginning of record for well.

Note: Cumulative Departure is based on the long-term average rainfall, 1956-2000, at the Bates Plumbing station in Arroyo Grande.

FIGURE 22 - TREND IN GROUNDWATER ELEVATIONS, NIPOMO VALLEY SUBBASIN WELLS



NET RISES AND DECLINES IN GROUNDWATER LEVELS

State Well No.	Periods of Above and Below Average Rainfall				Record through 1998	Record through 2000
	[a]1945-77	1978-83	1984-91	1992-98		
11N/34W-09P01	6.7[1970-75]	19.5[1980-83]	-29.5[1985-91]	64.4	27.6	11.0
11N/34W-17B04	-18.0	7.9	-72.7	52.2[1992-96]	-2.8[1974-96]	-1.6
11N/34W-05K01[a]		-1.6	-8.5[1985-91]	15.5	18.7	8.7

[a] Refer to hydrograph for beginning of record for well.

Note: Cumulative Departure is based on the long-term average rainfall, 1921-2000, at the Nipomo 2NW station.

However, only a part of the water in a saturated material will drain freely from rocks or sediments due to gravity. Specific yield describes the portion of the saturated pore space that could actually be available for extraction and is expressed as a percentage or decimal fraction. The volume of water retained in storage as a film on rock surfaces and in very small openings by molecular forces is termed specific retention and is also expressed as a percentage or decimal fraction. Specific retention increases with decreasing grain size.

Specific yield is sensitive to particle size, size distribution, and sorting. The smaller the grain size, the smaller the specific yield; the coarser the sediment, the greater the specific yield. Specific yields of unconfined aquifers may range from 1 to about 30 percent (Heath, 1983).

For confined aquifers, the deposits are not drained during pumping unless the hydraulic head drops below the top of the aquifer; therefore, a correlative term, storativity, is applied. Typical storativity values range from 10^{-5} to 10^{-3} (Heath, 1983). In unconfined aquifers, the storativity equals the specific yield.

In determining specific yield values for the Santa Maria Groundwater Basin, values based on the extensive work by the California Department of Public Works, Division of Water Resources (1934) and modified for the Paso Robles Formation by the Department (California Department of Water Resources, 1958) were used (Appendix C). Values were assigned to the types of materials penetrated as listed on lithologs of selected well completion reports of water wells throughout the basin. The assigned values were weighted by the thickness of the material penetrated and then the average weighted specific yield value for the well was calculated.

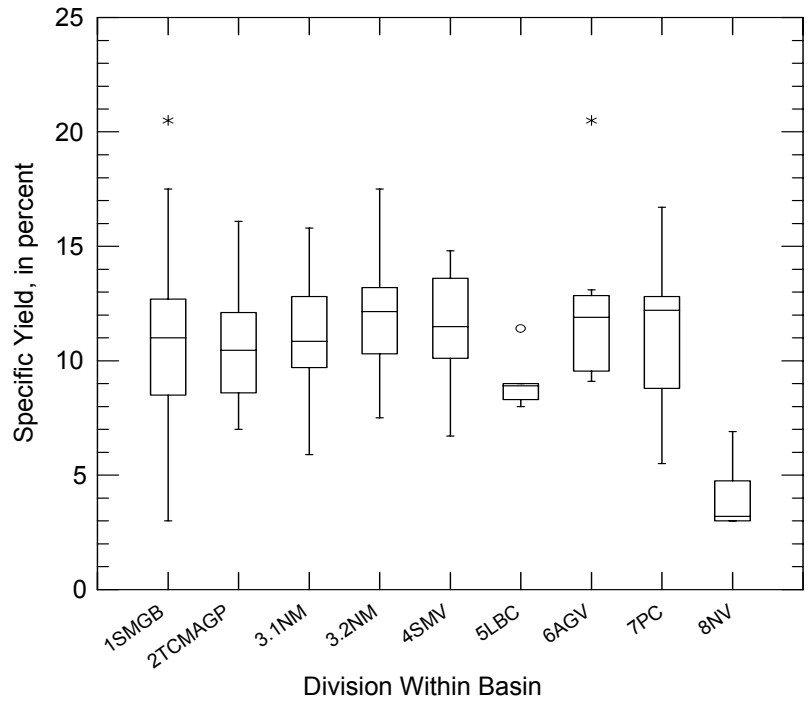
Table 16 presents the representative average weighted specific yield values determined for the

TABLE 16
AVERAGE WEIGHTED SPECIFIC YIELD, SANTA MARIA GROUNDWATER BASIN
In percent

Division Within Basin/Basin	N*	Average Weighted Specific Yield	
		Median Value	Range of Values
Oceano HSA**			
Tri-Cities Mesa - Arroyo Grande Plain	22	11	7-16
Los Berros Creek	5	9	8-11
Arroyo Grande Valley Subbasin	8	12	9-21
Pismo Creek Valley Subbasin	5	11	6-17
Nipomo Mesa HSA**			
Nipomo Mesa	44	12	6-18
Guadalupe HA**			
Santa Maria Valley	14	12	7-15
Nipomo Valley Subbasin	7	3	3-5
Santa Maria Groundwater Basin	113	12	3-21

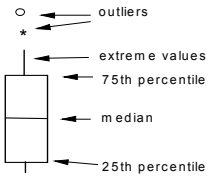
*N is the number of selected wells.
**Hydrologic area or subarea overlying groundwater basin.

FIGURE 23 - SPECIFIC YIELD VALUES, SANTA MARIA GROUNDWATER BASIN



EXPLANATION

1SMGB: Santa Maria Groundwater Basin
2TCMAGP: Tri-Cities Mesa - Arroyo Grande Plain
3.1NM: Nipomo Mesa, north of Santa Maria River fault
3.2NM: Nipomo Mesa, south of Santa Maria River fault
4SMV: Santa Maria Valley
5LBC: Los Berros Creek
6AGV: Arroyo Grande Valley Subbasin
7PC: Pismo Creek Valley Subbasin
8NV: Nipomo Valley Subbasin



Santa Maria Groundwater Basin and for divisions within the basin. Overall, the estimated median values found in the different portions of the main basin are similar. Nipomo Mesa and Arroyo Grande Valley Subbasin had the largest variation in specific yield values, ranging by 12 percent. Most of the wells on the mesa with the lower values are found north of the Santa Maria River fault. The median specific yield value for wells north of the fault is two percent lower than for wells south of the Oceano fault and about one-half percent lower than for wells between the Santa Maria River and Oceano faults.

Figure 23 illustrates the values given in Table 16 by means of "schematic box plots." On the figure, Nipomo Mesa was divided into two parts, north of Santa Maria River fault and south of the fault, to show the difference found in specific yield values for the basin sediments on each side of the fault.

The areal average weighted specific yield values estimated in this study for Nipomo Mesa and Santa Maria Valley are two to three percent lower than the average values determined in the Department's 1979 study. A probable explanation is that this study used the lower values of specific yield for the Paso Robles Formation (Appendix C) to assign to wells penetrating that formation, the Careaga Formation, and the Squire Member. More wells drilled since 1979 penetrate deeper into the older, usually "tighter," formations.

Storativity calculated from aquifer test analyses ranged from 0.001 to 0.0001, representative of semi-confined to confined conditions.

Table 17 shows the average weighted specific yield values estimated for the individual basin-fill deposits and formations. The alluvium and older dune sands were found to have the highest specific yield values and the older alluvium in Nipomo Valley Subbasin had the lowest specific yield values as a result of the high clay content of the deposit. The specific yield values for the Paso Robles Formation differed on opposite sides of the Santa Maria River fault, the median

TABLE 17
AVERAGE WEIGHTED SPECIFIC YIELD
BASIN-FILL DEPOSITS AND FORMATIONS
In percent

Deposit/Formation	Division Within Basin	N*	Average Weighted Specific Yield	
			Median Value	Range of Values
Holocene Alluvium	Arroyo Grande Plain	15	12	8-22
	Santa Maria Valley	11	13	9-23
	Arroyo Grande Valley Subbasin	8	12	9-21
	Pismo Creek Valley Subbasin	5	12	6-17
Older Dune Sand	Tri-Cities Mesa	10	13	5-22
	Nipomo Mesa	66	17	5-26
Older Alluvium	Nipomo Valley Subbasin	15	3	3-7
Paso Robles Formation	Tri-Cities Mesa - Arroyo Grande Plain	15	11	6-16
	Nipomo Mesa	67	8	4-20
	northeast of Santa Maria River fault	35	6	4-14
	southwest of Santa Maria River fault	32	10	4-20
	Santa Maria Valley	11	11	5-16
Careaga Formation	Nipomo Mesa	22	10	5-22
	Santa Maria Valley	5	8	5-26
Squire Member, Pismo Formation	Tri-Cities Mesa	18	10	6-16
	Nipomo Mesa	13	7	3-19

* N is the number of selected wells used.

value was two percent lower for the formation on the northeast side of the fault. The Careaga Formation was found to have specific yield values similar to the older dune sand in some wells.

Total Storage Capacity. The total volume of water that could theoretically be held in underground storage in the basin (not what is actually in storage at a given time) is quantified as total storage capacity. It is determined by multiplying the area overlying the basin by the total thickness and the average weighted specific yield ("specific yield method"). Total groundwater storage capacity takes into account only the theoretical physical capacity of the basin and not the many factors that can limit the ultimate development potential of the basin, such as quality, subsurface outflow, economic, environmental, or institutional limitations. However, estimates of total storage capacity can be useful for planning purposes.

Table 18 gives the total storage capacity estimates for the basin as a whole and for the divisions within the basin.[15] These estimates assume the basin-fill deposits can be saturated to within about 20 feet of ground surface. Estimated total storage capacity is given for both above msl and

TABLE 18
ESTIMATED TOTAL GROUNDWATER STORAGE CAPACITY* OF
SANTA MARIA GROUNDWATER BASIN, SAN LUIS OBISPO COUNTY
In acre-feet, unless otherwise noted

Division Within Basin/Basin	Surface Area, in acres	Average Weighted Specific Yield, in percent	Estimated Total Storage Capacity		
			Above MSL**	Below MSL**	Total
Oceano HSA***					
Tri-Cities Mesa - Arroyo Grande Plain+	10,770	11.0	52,000++	360,000++	412,000
Arroyo Grande Valley Subbasin	3,860	12.3	14,000++	0	14,000
Pismo Creek Valley Subbasin	1,220	11.2	2,000++	--	2,000
Nipomo Mesa HSA***					
Nipomo Mesa	17,580	11.7	490,000++	720,000++	1,210,000
Guadalupe HA***					
Santa Maria Valley	21,560	11.6	218,000++	2,100,000++	2,318,000
Nipomo Valley Subbasin	6,230	3.8	8,000++	0	8,000
Santa Maria Groundwater Basin	61,220		784,000	3,180,000	3,964,000

*Total storage capacity represents the total volume of water that could theoretically be held in underground storage.
**MSL is mean sea level.
***Hydrologic area or subarea overlying groundwater basin.
+Includes lower Pismo Creek and Los Berros Creek portions of the groundwater basin.
++Values rounded to two significant figures.

[15]Basin boundaries are shown on Plate 10.

below msl. A few points need to be mentioned. Because this method of estimating total storage capacity uses simplifying assumptions that may introduce errors of a few percent, the estimates in Table 18 were rounded to two significant figures. Errors can be introduced by using the median value of adjacent lines of equal elevation for the land surface and for the base of the basin as the representative elevation in the area between the lines. Also, the method uses the average weighted specific yield value to represent the system, both areally and vertically.

The estimated total storage capacity of the basin within San Luis Obispo County, both above and below msl, is about 4 million AF, of which about 20 percent is above msl. About half the total storage capacity of the groundwater basin, most of it below msl, is within Santa Maria Valley.

Of the estimated total storage capacity of Santa Maria Valley, only about 10 percent, or 218,000 AF, is above msl. Nipomo Mesa has the largest estimated total storage capacity for groundwater above msl, about one-half million AF, or about 40 percent of its total capacity. In Tri-Cities Mesa - Arroyo Grande Plain, about 15 percent, or 52,000 AF, of the estimated total storage capacity is above msl.

While the theoretical total storage capacity above msl for Nipomo Mesa is large, any development potential of this capacity would be limited by the need to avoid groundwater leakage from the edges of the mesa.

Estimated total storage capacity of the subbasins is small compared to that of the main basin, 24,000 AF, of which about 60 percent is in Arroyo Grande Valley Subbasin.

Groundwater in Storage. The amount of groundwater in storage at a given time depends on the volume of saturated sediments in the basin and the specific yield of those saturated sediments. The amount in storage is a constantly changing value, which fluctuates in response to both seasonal and long-term changes in recharge to and discharge from the groundwater basin as reflected by groundwater level changes.

Amounts in storage were estimated for Santa Maria Groundwater Basin for the springs of 1975, 1985, and 1995 using average weighted specific yield values estimated for the saturated thickness ("specific yield method").[16] The upper limit of saturation was determined from the groundwater elevation contour maps, Plates 12-14. Table 19 presents the estimated amounts in storage for the basin as a whole and for divisions within the basin, for both above and below msl.[17] The amount in storage above msl is important, because of the physical limitation placed on this coastal basin

[16]Amounts in storage were also estimated for spring 2000 for Santa Maria Groundwater Basin and are given in Table A1 in the addendum attached at the back of this report.

[17]Differences in amounts of groundwater in storage in this report from the January 2000 final draft report are because of changes in basin boundaries, base of the potentially water-bearing sediments, reference elevations of wells, groundwater elevation contours, and average weighted specific yield values (more well completion reports were available for this report).

TABLE 19
ESTIMATED AMOUNTS OF GROUNDWATER IN STORAGE
SANTA MARIA GROUNDWATER BASIN, SAN LUIS OBISPO COUNTY
In acre-feet, unless otherwise noted

Division Within the Basin/Basin	Surface Area, in acres	Average Weighted Specific Yield,[a] in percent	Water Year	Amount of Groundwater in Storage (Available Storage Capacity)			Change in Storage, Above MSL[b]	
				Above MSL[b]	Below MSL[b]	Total	Between Years	Amount
Oceano HSA[c]								
Tri-Cities Mesa - Arroyo Grande Plain[d]	10,770	11.0	1975	28,000[e]	360,000[e]	388,000	1975 and 1985	-1,000
			1985	27,000[e]	360,000[e]	387,000	1985 and 1995	2,000
			1995	29,000[e]	360,000[e]	389,000	1975 and 1995	1,000
Arroyo Grande Valley Subbasin	3,860	12.7	1975	9,000[e]	0	9,000	1975 and 1985	-1,000
			1985	8,000[e]	0	8,000	1985 and 1995	2,000
			1995	10,000[e]	0	10,000	1975 and 1995	1,000
Pismo Creek Valley Subbasin[f]	1,220			--	--	--		--
Nipomo Mesa HSA[c]	17,580	11.0	1975	84,000[e]	720,000[e]	804,000	1975 and 1985	-1,000
Nipomo Mesa			1985	83,000[e]	720,000[e]	803,000	1985 and 1995	-6,000
			1995	77,000[e]	720,000[e,g]	797,000	1975 and 1995	-7,000
Guadalupe HA[c]	21,560	11.1	1975	97,000[e]	2,100,000[e]	2,197,000	1975 and 1985	13,000
Santa Maria Valley			1985	110,000[e]	2,100,000[e]	2,210,000	1985 and 1995	-10,000
			1995	100,000[e]	2,100,000[e]	2,200,000	1975 and 1995	3,000
Nipomo Valley Subbasin	6,230	3.8	1975	3,600[e]	0	3,600	1975 and 1985	-500
			1985	3,100[e]	0	3,100	1985 and 1995	600
			1995	3,700[e]	0	3,700	1975 and 1995	100
Santa Maria Groundwater Basin	61,220		1975	221,600	3,180,000	3,401,600	1975 and 1985	9,500
			1985	231,100	3,180,000	3,411,100	1985 and 1995	-11,400
			1995	219,700	3,180,000	3,399,700	1975 and 1995	-1,900

[a] Specific yield values used for calculating amount of groundwater in storage were determined for only the saturated thickness of the basin.
[b] MSL is mean sea level.
[c] Hydrologic area or subarea overlying groundwater basin.
[d] Includes lower Pismo Creek and Los Berros Creek portions of the groundwater basin.
[e] Values rounded to two significant figures.
[f] Water level data were not available to determine amount in storage for the subbasin.
[g] A small amount of groundwater in storage was lost from below MSL because of the depression. It is not shown because of rounding to significant figures.

by the need to protect the basin from sea water intrusion. The table also presents the amount of change in storage above msl that took place between the three water years. This change shows only the difference for these three times and does not represent a steady year to year change. During the interim years, the amount of groundwater in storage fluctuated according to the amount of recharge and discharge that occurred in that portion of the basin.

The same limitations on accuracy apply to the estimates of amounts in storage, but the median value of adjacent lines of groundwater elevation is used to represent the water elevation in the area between the lines, rather than land surface elevation. Thus, the estimates in Table 19 have been rounded to two significant figures.

In 1995, within the San Luis Obispo County portion of the Santa Maria Groundwater Basin, the estimated amount of groundwater in storage, both above and below msl, was about 3.4 million AF, of which only about seven percent, or approximately 220,000 AF, was above msl. This amount is about 2,000 AF less than the amount in storage in 1975.

For Tri-Cities Mesa - Arroyo Grande Plain, the estimated amount of groundwater in storage, both above and below msl, for the three springs was nearly the same, 387,000 to 389,000 AF, of which 27,000 to 29,000 AF, or about six percent, were above msl. In this portion of the basin, the amount of groundwater in storage, between 1975 and 1985, declined 1,000 AF and between 1985 and 1995, increased 2,000 AF. The changes in storage coincide with hydrologic conditions, 1985 a dry year and 1995 a wet year, and also reflect stream infiltration.

In Nipomo Mesa, the amount of groundwater in storage in 1995, both above and below msl, was estimated to be about 800,000 AF, of which 77,000 AF, or about 10 percent, were above msl. The 1995 amount above msl is about eight percent less (6,000 AF) than the amount in storage above msl in 1985. Because Nipomo Mesa's major source of recharge is deep percolation of precipitation, the loss in storage reflects variations in hydrologic conditions. The average rainfall during the period from water year 1985 through water year 1995 was about two inches less than the average rainfall during the period from water year 1975 through water year 1985. Also, the loss is primarily associated with those areas of pumping depressions shown on Plate 14 and declining trends found in groundwater levels in some wells in parts of the mesa. As mentioned earlier, the magnitude of the depression in the south-central part of the mesa is not well defined because wells with groundwater level data are limited and reference elevations for all the wells were not surveyed. The mesa also showed a small decline in storage above msl of 1,000 AF between 1975 and 1985.

Santa Maria Valley was estimated to have 2.2 million AF of groundwater in storage in 1995, both above and below msl, of which 100,000 AF, or about five percent, were above msl. This amount is 3,000 AF more than the estimated amount in storage in spring 1975. In 1985, the valley was estimated to have 110,000 AF of groundwater in storage above msl, 13,000 AF more than 1975, because of the 1983 wet year and substantial stream infiltration from the Santa Maria River that year and from Twitchell Reservoir releases in 1984. Stream infiltration from the Santa

Maria River in the 1995 wet year was not yet fully reflected in groundwater elevations in the valley that year. Based on the trend in groundwater elevations, the amount in storage increased in the succeeding years as the recharge mound traveled away from the river. Part of the change in storage from 1985 to 1995 in Santa Maria Valley reflects movement of groundwater from the valley into Nipomo Mesa (shown by the pumping depression on Plate 14).

Arroyo Grande Valley Subbasin was estimated to have 8,000 to 10,000 AF of groundwater in storage. The subbasin had a loss in storage in the 1985 dry year and a small gain in storage in the wet year 1995.

Water level data were not available to estimate an amount of groundwater in storage in Pismo Creek Valley Subbasin.

Nipomo Valley Subbasin was estimated to have 3,100 to 3,700 AF of groundwater in storage in the older alluvium and Orcutt Formation. The subbasin had a loss in storage in the 1985 dry year and a small gain in storage in the wet year 1995.

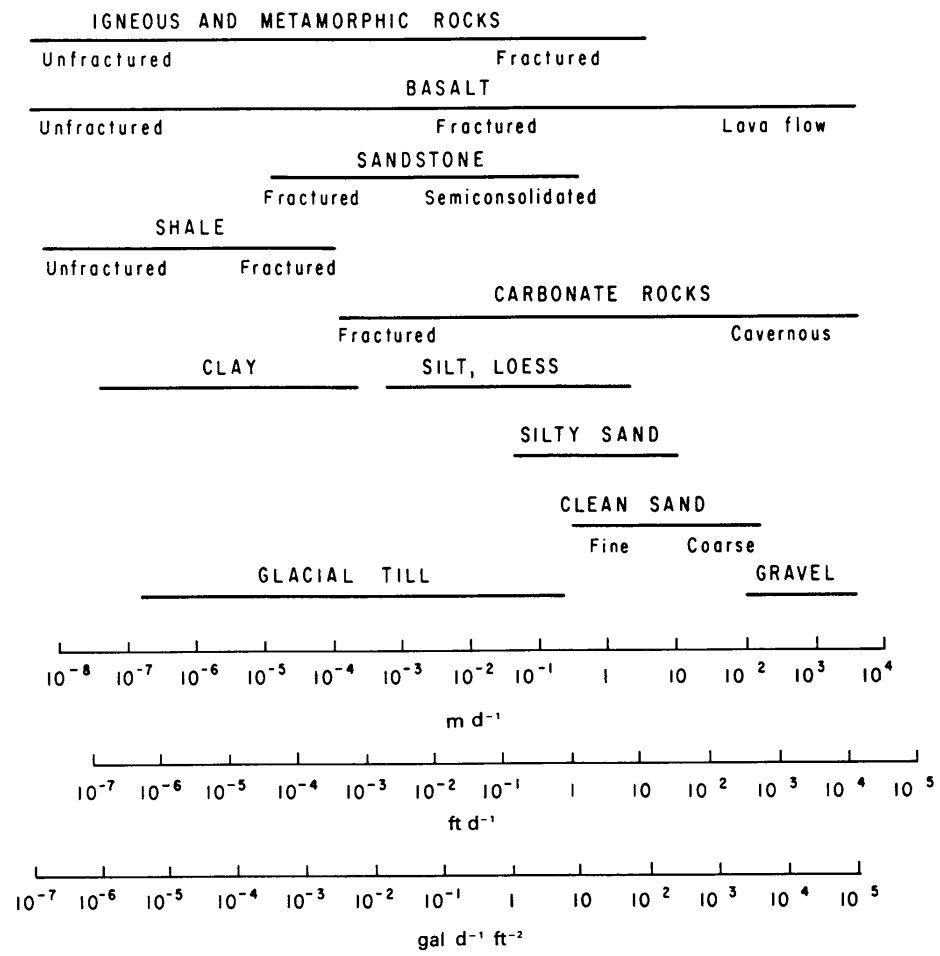
Because of the very wet year 1998, the estimated amount of groundwater in storage above msl in the basin in 2000 was 40,000 AF more than the 1995 amount and about 38,000 AF more than the 1975 amount. Estimated amounts above msl in the basin were: 30,000 AF in the Tri-Cities Mesa - Arroyo Grande portion of the basin, 84,000 AF in the Nipomo Mesa portion of the basin (this is the same amount as in 1975 despite the continued presence of the pumping depression in the south-central part on the mesa, Plate A1 in the Addendum), 132,000 AF in the Santa Maria Valley portion of the basin, 10,000 AF in Arroyo Grande Valley Subbasin, and 3,700 AF in Nipomo Valley Subbasin. (See Table A1 in the Addendum.)

In the Santa Maria Groundwater Basin, a dynamic balance exists between recharge and discharge, as the basin continuously seeks a new equilibrium. Changes in the amount of groundwater in storage are the response of the basin to variations in hydrologic conditions and recharge and discharge and to changes in land and water uses within the basin. Recharge to the Tri-Cities Mesa - Arroyo Grande Plain portion of the basin is augmented by stream infiltration from Lopez Reservoir releases and to the Santa Maria Valley portion of the basin by stream infiltration from Twitchell Reservoir releases. Because Nipomo Mesa's only major source of recharge is deep percolation of precipitation, this part of the basin is more susceptible to prolonged dry periods and increasing demands on its groundwater supplies. To protect the basin from sea water intrusion, it is important that the amount of groundwater in storage in the basin be of sufficient quantity for the freshwater head to counterbalance the greater density of sea water and subsurface outflow to the ocean to occur.

Hydraulic Conductivity and Transmissivity

The hydraulic properties of an aquifer that quantify the rate at which groundwater flows are called hydraulic conductivity and transmissivity.

FIGURE 24 - HYDRAULIC CONDUCTIVITY OF SELECTED ROCKS



From: Heath, R. C., 1983

Hydraulic conductivity is a measure of the quantity of water that flows per day through a square foot cross-section of an aquifer under a hydraulic gradient of one to one. It is governed by the size and shape of the pores, the effectiveness of the interconnection between pores, and the physical properties of the fluid. The more hydraulically conductive material has larger, more completely connected pores than does the less conductive material.

Hydraulic conductivity of rocks has been found to range over 12 orders of magnitude (Heath, 1983). It not only is different in different types of rocks, but also may be different from place to place within the same material. Figure 24 illustrates the range in magnitude of hydraulic conductivity of various materials determined in thousands of tests by the USGS.

In most rocks, hydraulic conductivity is not equal in all directions, but is most commonly greater

in the horizontal direction than in the vertical direction (Heath, 1983). Vertical conductivity, which governs infiltration rates, is typically 0.1 to 0.01 times the horizontal conductivity (Lohman, 1972).

Transmissivity is a measure of the quantity of water flowing through a 1-foot-wide cross-section of the saturated thickness of the aquifer under a hydraulic gradient of one to one. It is the product of the hydraulic conductivity of the saturated aquifer times the thickness of the saturated aquifer. The effective transmissivity of an aquifer does not remain constant, but changes with increases or decreases in the saturated thickness of the aquifer.

Values of hydraulic conductivity and transmissivity for the Santa Maria Groundwater Basin were estimated using data obtained by three methods: (1) aquifer hydraulic test data, (2) pump efficiency data, and (3) lithologic correlation assignment of hydraulic conductance values to the types of material penetrated as reported on the lithologs of well completion reports. The three methods are described in Appendix C.

Table 20 illustrates the degree to which hydraulic conductivity values can vary for the basin-fill deposits of the Santa Maria Groundwater Basin. The great lithologic heterogeneity of the deposits, consisting of varying mixtures of clay, silt, sand, gravel, and boulders in discontinuous lenses, causes correspondingly large variations in hydraulic conductivity. Because of this heterogeneity, no one value can be truly representative of a deposit, formation, or division within the basin. The highest hydraulic conductivity values are generally found in the alluvium. Lower conductivity values are generally found in the oldest formations--the Careaga Formation and the Squire Member of the Pismo Formation. Also, lower values of conductivity tended to be found in the basin deposits north of the Santa Maria River fault underlying Nipomo Mesa.

Aquifer transmissivities of the basin were found to range over several orders of magnitude, from 100 to more than 400,000 gallons per day per foot. Transmissivity values of the alluvial aquifers in Santa Maria Valley were the highest, ranging from 200,000 to 400,000 gallons per day per foot. In Arroyo Grande Valley, values of the alluvial aquifers were as high as 100,000 gallons per day per foot. Transmissivity values of the Paso Robles Formation ranged from 100 to 160,000 gallons per day per foot. The higher values for the formation were found south of the Oceano fault, in both Nipomo Mesa and Santa Maria Valley parts of the basin. Values for the Paso Robles Formation in Tri-Cities - Arroyo Grande Plain ranged from 20,000 to 130,000 gallons per day per foot. Transmissivity of the Squire Member in Tri-Cities Mesa - Arroyo Grande Plain ranged from about 3,000 to 30,000 gallons per day per foot. The Careaga Formation had transmissivity values similar to those for the Paso Robles Formation. The lowest transmissivity values are typically found in the Nipomo Mesa part of the basin, north of the Santa Maria River fault, where values ranged from 100 to about 4,000 gallons per day per foot.

Subsurface Flows

Within the basin, groundwater flows from recharge areas to discharge areas. Groundwater flows

TABLE 20
ESTIMATED HYDRAULIC CONDUCTIVITY
SANTA MARIA GROUNDWATER BASIN, SAN LUIS OBISPO COUNTY
In gallons per day per foot squared

Deposit/Formation	Division Within Basin	Hydraulic Conductivity*		
		Aquifer Test	Pump Efficiency	Lithologic Correlation
Alluvium	Arroyo Grande Plain		700-2,000	40-4,200
	Arroyo Grande Valley Subbasin	2,000	9-90	165-5,800
	Santa Maria Valley	2,000-3,500	5,200-6,000	50-6,800
Alluvium and Paso Robles Formation	Santa Maria Valley	1,500**	55-1,000	
Older Alluvium	Nipomo Valley Subbasin		115-255	<1-20
Paso Robles Formation	Tri-Cities Mesa - Arroyo Grande Plain	370-900	120-2,700	5-2,900
	Nipomo Mesa	22-540	1-375	5-800
	Santa Maria Valley	65***	10-1,035	20-2,000
Paso Robles and Careaga Formations	Nipomo Mesa	10-50	15-90	
Paso Robles Fm and Squire Member	Tri-Cities Mesa	50-130	130-450	
	Nipomo Mesa		1-45	
Careaga Formation	Nipomo Mesa			<1-235++
	Santa Maria Valley	75+		<1-320++
Squire Member	Tri-Cities Mesa	30-40	20-110++	3-325++
	Nipomo Mesa		1-10++	<1-200++

*Value or range of values given for each method used to estimate hydraulic conductivity.

**Worts (1951) determined the hydraulic conductivity based on recovery tests.

***Worts (1951) determined the hydraulic conductivity of the Paso Robles Formation from the results of one recovery test from one pumped well, which penetrates only a part of the Paso Robles Formation.

+Upson and Thomasson (1951) collected 12 samples of the Careaga Formation from outcrops in central Santa Barbara County, which were tested for permeability in the laboratory. The hydraulic conductivity values ranged from 7 to 89 gallons per day per foot squared in four samples, with an average of 70 gallons per day per foot squared at 60° F, which they believed represented the approximate order of magnitude of the formation (Upson and Thomasson, 1951, p. 34). Citing belief of similarity of lithologic properties, Worts (1951) extrapolated this hydraulic conductivity value for the Careaga Formation for use within the Santa Maria Valley. He adjusted the laboratory-derived value of 70 gallons per day per foot squared to a field temperature value of 65° F, with the resultant conductance value being 75 gallons per day per foot squared. This value of hydraulic conductivity of the Careaga Formation continues to be used in studies as the value of this formation.

++Wells did not penetrate full thickness of the formation.

from the main basin to the Pacific Ocean. Within the main basin, groundwater flows from Nipomo Mesa to Arroyo Grande Plain and, depending on groundwater elevations and hydraulic gradients in Nipomo Mesa, groundwater may flow from Santa Maria Valley in San Luis Obispo County to Nipomo Mesa. Also, groundwater flows from Arroyo Grande Valley and Pismo Creek Valley Subbasins to the Tri-Cities Mesa - Arroyo Grande Plain portion of the main basin and possibly from Nipomo Valley Subbasin to the Nipomo Mesa portion of the main basin. As mentioned earlier, hydraulic connection across the Wilmar Avenue fault in Nipomo Valley is not known. Groundwater may also flow into the basin from the surrounding bedrock and, in Santa Maria Valley, from the upstream portion of the basin, outside the study area[18]. Amounts of subsurface flows were estimated for water years 1975, 1985, and 1995 of the study period.

The method used to estimate subsurface flows is based on Darcy's law of saturated flow. For this, it is necessary to know the cross-sectional area of the basin-fill deposits through which the subsurface flow occurs, the hydraulic conductivity of the deposits, and the hydraulic gradient. Because of the high degree of variability of hydraulic conductivity of the deposits, estimated low, high, and geometric mean[19] values of hydraulic conductivity for deposits along the cross-section were used to calculate subsurface flow amounts. Hydraulic gradients were computed for 1975, 1985, and 1995 from Plates 12-14. The estimated quantities of subsurface flows thus derived for this study are presented in Table 21.

Subsurface Outflows to the Ocean. Geologic cross-section A-A′ (Plate 3) was used to determine the area through which the subsurface outflow to the ocean takes place. The total saturated cross-sectional area was about 50 million square feet. The estimated mean amount of outflow from the basin to the ocean was about 10,000 AF each year.

The largest estimated amounts of outflow to the ocean are from Santa Maria Valley, where the depth of the basin is greatest and the alluvium has a high hydraulic conductivity. Estimated amounts ranged from a low amount of 1,800 AF in 1975 and 1995 to a high amount of 23,000 AF in 1985, with estimated mean amounts of about 6,000 AF in 1975 and 1995 and about 7,000 AF in 1985. About two-thirds of the estimated amount of outflow from the valley to the ocean occurs through the alluvium. The slightly higher estimated outflow from Santa Maria Valley in 1985 was the result of an increased hydraulic gradient from higher groundwater elevations (a greater amount of groundwater was in storage because of substantial stream infiltration from the Santa Maria River in the 1983 wet water year and from Twitchell Reservoir releases in 1984).

[18]The Santa Maria Valley portion of the main basin may also be recharged by some subsurface inflow from the southern end of Nipomo Valley Subbasin, but data are insufficient to estimate amounts and hydraulic connection across the Wilmar Avenue fault is not known.

[19]The geometric mean is determined by taking the natural log of each value, finding the mean of the natural logs, and then obtaining the exponential of that value. Detailed work on distributions of hydraulic conductivity values by Cardwell and Parsons (1945), Warren and Price (1961), and Bennion and Griffiths (1966) determined that the average conductance value lies between the harmonic and arithmetic means and is best described by the geometric mean.

TABLE 21
ESTIMATED SUBSURFACE FLOWS
SANTA MARIA GROUNDWATER BASIN, SAN LUIS OBISPO COUNTY
In acre-feet

Subsurface Flows	Division Within the Basin/Basin	Water Year	Estimated Amounts		
			Low Amount	High Amount	Geometric Mean Amount
Outflows to the Ocean	Tri-Cities Mesa - Arroyo Grande Plain*	1975	1,000	10,000	3,200
	Nipomo Mesa		270	2,700	880
	Santa Maria Valley		1,800	18,000	5,700
	Groundwater Basin Total		3,070	30,700	9,780
	Tri-Cities Mesa - Arroyo Grande Plain*	1985	900	9,000	2,800
	Nipomo Mesa		150	1,500	470
	Santa Maria Valley		2,300	23,000	7,300
	Groundwater Basin Total		3,350	33,500	10,570
	Tri-Cities Mesa - Arroyo Grande Plain*	1995	1,100	11,000	3,700
	Nipomo Mesa		210	2,100	670
	Santa Maria Valley		1,800	18,000	5,700
	Groundwater Basin Total		3,110	31,000	10,070
Flows Within the Basin	Nipomo Mesa to Arroyo Grande Plain	1975, 1985, 1995	560	4,300	1,300
	Santa Maria Valley to Nipomo Mesa**	1985	570	2,500	1,200
		1995	1,200	5,100	2,500
	Arroyo Grande Valley Subbasin to Tri-Cities Mesa - Arroyo Grande Plain*	1975 & 1995	420	4,200	1,300
		1985	340	3,400	1,100
	Pismo Creek Valley Subbasin to Tri-Cities Mesa - Arroyo Grande Plain*	1975, 1985, 1995	30	320	100
	Nipomo Valley Subbasin to Nipomo Mesa	1975, 1985, 1995	160	1,600	500
Flows Into the Basin	Inflow from bedrock to Tri-Cities Mesa	1975, 1985, 1995	520	5,100	1,600
	Inflow from upstream (outside study area) to Santa Maria Valley	1975	580	3,500	1,400
		1985	940	5,600	2,300
		1995	670	4,000	1,600

*Includes lower Pismo Creek and Los Berros Creek portions of the groundwater basin.
**Subsurface flow from Santa Maria Valley to Nipomo Mesa will occur depending on groundwater elevations and hydraulic gradients.

Estimated amounts of outflow from Tri-Cities Mesa - Arroyo Grande Plain to the ocean were about half the outflow that occurs from Santa Maria Valley. Estimated amounts ranged from a low amount of 900 AF in 1985 to a high amount of 11,000 AF in 1995, with estimated mean amounts of about 3,000 AF in 1975 and 1985 and about 4,000 AF in 1995. About 40 percent of the outflow occurs through the alluvium of Arroyo Grande and Pismo Creeks.

The smallest estimated amounts of outflow to the ocean occur from Nipomo Mesa. Estimated amounts ranged from a low amount of 150 AF in 1985 to a high amount of 2,700 AF in 1975, with estimated mean amounts of about 900 and 500 AF in 1975 and 1985, respectively, and about 700 AF in 1995.

Subsurface Flows within the Basin. To determine subsurface flow from Nipomo Mesa to Arroyo Grande Plain, a north-south cross-sectional area, cutting the edge of the mesa bordering the plain, was used to define the area through which the flow occurs. The total saturated cross-sectional area was about 3.75 million square feet. Because the hydraulic gradient was the same for all three years, the estimated flow amounts were the same, with a mean amount of 1,300 AF.

To determine subsurface flow from Santa Maria Valley to Nipomo Mesa in 1995, an east-west cross-section area cutting the basin near the southern edge of the depression shown on Plate 14 was used to define the area through which the flow takes place. The total saturated cross-sectional area was about 10.8 million square feet. The mean estimated amount of subsurface flow in 1995 was 2,500 AF, with a range of 1,200 to 5,100 AF. The saturated cross-sectional area for flow in 1985 was about 2.2 million square feet and the mean amount of subsurface flow was estimated to be 1,200 AF. Cleath & Associates (1996a) had estimated an average of 3,300 AFY of groundwater to flow from the valley to the mesa between 1977 and 1992, which is within the 1995 range estimated in this study. Subsurface flow will occur from the valley to the mesa depending on the lateral extent of the pumping depression in the mesa and groundwater elevations and hydraulic gradients.

To determine subsurface flow from the subbasins to the main basin, cross-sectional areas along the Wilmar Avenue fault were used to define the area through which flow takes place. The total saturated cross-sectional area for Arroyo Grande Valley Subbasin was about 200,000 square feet. The mean amount of subsurface flow was estimated to be about 1,300 AF in 1975 and 1995 and 1,100 AF in the dry year 1985. The total saturated cross-sectional area for Pismo Creek Valley Subbasin was about 100,000 square feet. Based on limited data, the mean amount of subsurface flow is estimated to be 100 AF each of the three years. The total saturated cross-sectional area for Nipomo Valley Subbasin was about 1 million square feet. If hydraulic continuity occurs across the Wilmar Avenue fault between Nipomo Valley Subbasin and Nipomo Mesa, the mean subsurface flow amount into the mesa from the valley was estimated to be 500 AF each of the three years.

Subsurface Flows into the Basin. To determine subsurface flows into the basin from the bedrock and from upstream in Santa Maria Valley outside the study area, two saturated cross-

sectional areas were used. These are the edge of the basin along the San Luis Range, which is about 3 million square feet, and across the Santa Maria River east of Highway 101 in Santa Maria Valley along the study area boundary, which is about 125,000 square feet. Mean subsurface flows into the Tri-Cities Mesa part of the basin from bedrock were estimated to be 1,600 AF each of the three years. Mean subsurface flows into Santa Maria Valley from upstream were estimated to be 1,400 and 1,600 AF in 1975 and 1995, respectively. The estimated mean flow into Santa Maria Valley in 1985, about 2,300 AF, was greater because of an increased hydraulic gradient from higher groundwater elevations.

Groundwater in Bedrock

Evaluating groundwater conditions in the bedrock of the study area is challenging because of the complex geology and limited data available. These rocks are significant for their role as sources of local groundwater supply and as natural recharge for the groundwater basin. The areas overlying bedrock are also seeing increasing development and associated utilization of groundwater. Given the typically limited capacity of bedrock to store and transmit groundwater, documenting what is known is important.

The occurrence and movement of groundwater in bedrock largely depend on the number of openings in the rock and their degree of interconnection. Primary openings created at the time the rock formed include pores in sedimentary rocks and vesicles and cooling fractures in volcanic rocks. The number of primary openings depends on sorting, grain shape, packing, and degree of cementation, with cementation the most important because it can reduce the interconnectivity of the pores. Fracturing, weathering, and solution after the rock formed produce secondary openings. The number, spacing, size, orientation, and degree of interconnection of the secondary openings are important for controlling both the hydraulic conductivity and storage capacity of the bedrock mass.

The bedrock aquifers within the study area consist primarily of the semi-consolidated sandstone Pismo Formation, the consolidated shale Monterey Formation, and the volcanic tuff and lava Obispo Formation.[20] The Pismo Formation is found in the area north of the Wilmar Avenue fault and Tar Spring Creek and west of the Edna fault zone. The Monterey and Obispo Formations are mainly found south of the northern alluvial contact of Tar Spring Creek and east of the Wilmar Avenue fault, including the area underlying the older alluvium in Nipomo Valley Subbasin. The main groundwater development in the subbasin is in the Obispo and Monterey Formations. (See Plate 2 for location of these formations.)

Pismo Formation

Within the area northwest of Arroyo Grande Valley and Tar Spring Creek, the Pismo Syncline is

[20]Lithologic descriptions of these formations are given in Chapter II.

the primary geologic control for groundwater. Groundwater is found within the Pismo Formation, a semi-consolidated to consolidated rock aquifer, with groundwater in storage in both interstices in the sediments and in fractures. Available well completion reports do not indicate groundwater being extracted from the shallow alluvial fill that blankets the floors of the canyons.

A review of well completion reports of wells drilled in this area provides some information on depths of the wells and the yields obtained. Wells were drilled to depths of 1,040 feet, but most are not deeper than 500 feet and half are less than 300 feet. Yields typically ranged from 10 to 100 gallons per minute, with half the wells yielding less than 30 gallons per minute. A few well completion reports of wells less than 100 feet deep indicated yields as only very little.

Movement of the groundwater locally follows the topography, ultimately moving west-southwesterly into the adjoining Santa Maria Groundwater Basin.

Groundwater is recharged mainly by intermittent deep percolation of precipitation and runoff and is discharged by well extractions, evapotranspiration, and subsurface outflow to the adjoining groundwater basin.

Specific yield values were estimated for the Pismo Formation from selected wells using the same method as for the groundwater basin. Values were estimated to range from 5 to 20 percent, with a median value of 10 percent.[21]

The hydraulic conductivity of sandstone is one to four orders of magnitude lower than the values for unconsolidated sand (Figure 24). It has been found that, as the porosity of a sandstone decreases, particularly below 15 percent, the permeability depends more on the presence of interconnected fractures than on the original porosity within the rock (Davis, 1988).

Transmissivity values for a few wells with pumping test data ranged from 240 to about 2,400 gallons per day per foot and hydraulic conductivity values ranged from one gallon to about 120 gallons per day per foot squared. These conductivity values are similar to those found from pump efficiency tests for the Squire Member and the Careaga Formation in the groundwater basin (Table 20).

Values of hydraulic conductivity for the Pismo Formation in this area were also determined for selected wells by the lithologic correlation method (described in Appendix C). The values estimated by this method for the formation ranged from one gallon to about 1,000 gallons per day per foot squared.

Two reports reviewed for this study evaluated the Pismo Formation. A 1988 report by RRM Design Group gave information on an investigation of the potential groundwater supply for a

[21]The values estimated in this bedrock area are similar to those found for the Squire Member within the Tri-Cities Mesa part of the groundwater basin.

154-acre parcel north of Highway 101 and west of Oak Park Boulevard. A 1999 report by Firma included information from a water supply study by Cleath & Associates (1998b) of the deep aquifer of the Pismo Formation in an area of about 86 acres north of Highway 101 and between Oak Park Boulevard and Corbit Canyon Road (Village Glen).

RRM Design Group reported that, in general, porosity and permeability of the Pismo Formation at the site are very good. The 1988 report included the following excerpts from a Cleath & Associates report on a preliminary groundwater study made for RRM Design Group:

> "[T]he lower aquifer is a blue fine-grained sandstone about 300 feet thick which appears to be dipping to the northeast at about 14 degrees. The drilling penetration rate in the sand bed is much faster than the overlying siltstone. This aquifer is recharged by surface water in the Oak Park Valley and adjacent canyons. The ground water in this aquifer is confined below a siltstone aquitard and is under pressure, resulting in relatively shallow water levels." (RRM Design Group, 1988, p. 33)
>
> "The lower, fine-grained sandstone aquifer holds the best potential for good well yields on the property. The upper medium coarse-grained sandstone aquifer also yields some water to wells, but the yield could be influenced by interference from adjacent producing wells and seasonal water level fluctuations." (Ibid., p. 34)

The RRM Design Group (1988, p. 33) also stated that Cleath & Associates had estimated aquifer storage for the site at "more than 50,000 acre feet of water."

Based on test hole information in the Village Glen area, Cleath & Associates (1998b) identified a deep aquifer in the Pismo Formation, lying below ground surface at a depth of about 600 feet and with a maximum thickness of about 300 feet. The aquifer was described as composed of olive brown, loose, clean, fine-grained sand and was estimated to have a transmissivity of 620 gallons per day per foot and hydraulic conductivity of three gallons per day per foot squared. Groundwater in storage in the deep aquifer at the site was estimated to be 19,000 to 50,000 AF, based on average aquifer thickness. It was noted that the aquifer has restricted ability to transmit water and to release water from storage (Cleath & Associates, 1998b).

Using the median specific yield value of 10 percent and a thickness of 300 feet for the Pismo Formation, the total groundwater storage capacity for the area northwest of Arroyo Grande Valley and Tar Spring Creek was estimated to be possibly about 270,000 AF.

Monterey and Obispo Formations

In the area south of Tar Spring Creek and east of the Wilmar Avenue fault, groundwater is found in the Monterey and Obispo Formations. The water-bearing characteristics of fractured rock and volcanic rock are varied and more complex than are those of the members of the Pismo Formation.

The Monterey Formation is predominantly a fine-grained rock mass and the intergranular permeability is very low. Fracturing is important for the storage and transmission of groundwater in this formation. Lithologs on well completion reports sometimes indicated layers of soft shale. Soft shale may not retain significant fracture openings below about 100 feet (Davis, 1988). Possible closure of fractures below 100 feet is important for availability of groundwater. However, Isherwood (1981) determined that, if Monterey shale is brittle with large amounts of silica, it could maintain abundant open fractures at depths greater than about 900 feet.

Not only the different geodynamic emplacement and geologic processes, but also different hydrologic factors cause significant hydrogeologic variability in volcanic rocks. The Obispo Formation in the study area is primarily tuffs and lavas, locally cut by dikes or sills. Tuff is a pyroclastic deposit, with a wide range of particle sizes, sorting, and fracture densities. Fracturing, which increases both porosity and hydraulic conductivity, is a major geologic control on the flux of groundwater in both the tuffs and lavas.

The most extensive groundwater assessment of the Obispo Formation fractured tuff was conducted by Cleath & Associates (1995) as part of a groundwater management study for the Bartleson Development Plan in Los Berros Canyon near Highway 101. In that study, Cleath & Associates found that two resistant tuff members contain groundwater-yielding zones corresponding to fractured strata. They also found that the interbedded black shales did not yield groundwater readily. Within the study area, Cleath & Associates estimated that about one-fourth the total volume of the Obispo Formation yielded groundwater readily.

Groundwater is recharged mainly by intermittent deep percolation of precipitation and runoff and is discharged by well extractions, evapotranspiration, and possibly subsurface outflow to the adjoining Santa Maria Groundwater Basin; however, the potential hydraulic continuity across the Wilmar Avenue fault is unknown.

Available well completion reports of wells provide some information on the occurrence of groundwater in the Monterey and Obispo Formations.

Underlying the alluvium of Tar Spring Creek, west of the West Huasna fault zone, wells mainly extract groundwater from fractured Monterey shale drilled to depths of about 100 feet. Yields from these wells ranged from 10 to 400 gallons per minute, with half the wells having a yield of less than 50 gallons per minute. Groundwater movement locally follows topography and ultimately is westward.

Wells in Nipomo Valley Subbasin and the adjacent highlands extract groundwater from either the Obispo or Monterey Formation. Based on available well completion reports, wells drilled into the Obispo Formation ranged in depth from 130 to 875 feet, with half the wells greater than 400 feet. Yields ranged from 5 to 750 gallons per minute, with half the wells yielding less than about 60 gallons per minute. About one-third of the boreholes drilled into the Obispo Formation were "dry." Wells drilled into the Monterey Formation ranged in depth from about 75 to 540 feet,

with half more than 250 feet. Well yields ranged from 5 to 460 gallons per minute, with half yielding less than 80 gallons per minute. About 10 percent of the boreholes drilled into the formation were "dry."

Depth to water ranged from land surface to about 300 feet, with many wells showing evidence of confining pressures in both formations. Figure 22, presented earlier in this report, shows water level hydrographs of wells perforated in the Monterey Formation in Nipomo Valley Subbasin.

Based on laboratory and field tests, Winograd and Thordarson (1975) reported that values of hydraulic conductivity for fractured and nonfractured tuffs, zeolotized tuffs, and tuffs altered to clay spanned eight orders of magnitude, from 10^{-6} to 10^{2} gallons per day per foot squared. Figure 24 shows that the hydraulic conductivity for basalt, one of the types of lava in the Obispo Formation, ranges over 12 orders of magnitude.

Isherwood's field determinations (1981) of hydraulic conductivity of fractured Monterey shale found the values to be comparable to those of sandstones, that is, about 180 to 180,000 gallons per day per foot squared.

On the basis of a four-hour pump test of the fractured tuff reservoir, Cleath & Associates (1995) calculated a storativity of 0.0009 for the fractured tuff and a transmissivity of 37,500 gallons per day per foot (hydraulic conductivity of about 65 gallons per day per foot squared). They estimated about 3,300 AF to be in storage at the site during wet years, based on an effective base of 100 feet below msl.

Based on four pump efficiency tests of wells perforated in bedrock in Nipomo Valley Subbasin, hydraulic properties of the Monterey and Obispo Formations were estimated using the modified Thiem formula. Transmissivity of the Monterey Formation was estimated to range from 3,000 to 5,200 gallons per day per foot and hydraulic conductivity was estimated to range from 15 to 25 gallons per day per foot squared for aquifer thicknesses of 175 to 350 feet. These estimated conductivity values are lower than those determined by Isherwood. Transmissivity for the Obispo Formation was estimated from one well to be 8,500 gallons per day per foot and hydraulic conductivity to be 85 gallons per day per foot squared for a thickness of 100 feet.

Specific yield values of selected wells penetrating the Monterey Formation were estimated to range from three to five percent and for the Obispo Formation from three to six percent, with median values of four percent for both formations. The total groundwater storage capacity of the two formations was estimated to be possibly about 360,000 AF.

Artificial Recharge

Artificial recharge is the replenishing of groundwater by means primarily provided for that purpose. The principal benefits of artificial recharge may be relief of adverse conditions from

overdevelopment of the resource or increase in the quantity, or yield, of groundwater available for use. Artificial recharge is accomplished through works designed to maintain high infiltration capacities, increase the wetted area, and lengthen the period of infiltration beyond that which exists under natural conditions (Richter and Chun, 1959). Projects commonly utilize various combinations of the following general methods: (1) surface spreading of water by putting it in basins or ponds, ditches, and furrows, by flooding, or by modifying streambeds and (2) diverting water into pits or shafts and injection wells.

Another method is an *in lieu* project. This method leaves water underground and supplies surface water directly to users.

Use of a particular method or combination of methods and selection of a site or sites depends on such factors as: (1) availability of a water supply of suitable quality for recharge; (2) topographic, geologic, and surface and subsurface hydrogeologic conditions suitable for maintaining high infiltration rates and storing water; (3) position and hydraulic gradient of the existing water table or potentiometric surface; (4) transmissivity; (5) availability of land; (6) costs; (7) environmental concerns; and (8) operation and maintenance. The method used and area selected, therefore, should be those that best fit local conditions.

Artificial recharge (*in lieu* method) has been operating for more than 30 years in the study area. Surface water from Lopez Reservoir is supplied to agencies that would otherwise extract groundwater from the Tri-Cities Mesa -Arroyo Grande Plain part of the Santa Maria Basin.

Potential artificial recharge projects have been identified for the study area. These include:

- Lawrance, Fisk & McFarland, Inc., (LFM, 1985a,b,c) conducted a conjunctive use study for San Luis Obispo County Flood Control and Water Conservation District in which potential artificial recharge projects for Tri-Cities Mesa were identified. These potential projects were in-stream check dams and injection wells.

  In-stream check dams on Arroyo Grande Creek were identified as a possible means of enhancing infiltration capability by creating shallow ponds during periods of low to moderate streamflow. Hoover & Associates, Inc. (1985b), under contract with LFM, proposed four dams and calculated that 800 AFY could be recharged by this project. Although this project appears hydrologically and hydrogeologically feasible, environmental concerns would have to be addressed if it is undertaken.

  The proposed injection well project involved conveying surplus Lopez Reservoir water through the existing distribution systems of contracting cities on Tri-Cities Mesa to well fields for injection near wells producing from the Squire Member of the Pismo Formation. LFM assumed theoretical monthly injection rates could average between 20 and 300 AF per month. Cost is a major consideration with injection well projects; however, environmental concerns associated with in-stream check dams can be avoided.

LFM (1985b) estimated that when groundwater in storage in the Tri-Cities Mesa - Arroyo Grande Plain portion of the basin is 80 percent of total, slight rejection of recharge from Arroyo Grande Creek occurs. The rejection rate then increases as the basin continues to fill. They also noted that whenever there is sufficient natural water supply for Lopez Reservoir to fill, there has also been sufficient supply to recharge the basin in Tri-Cities Mesa - Arroyo Grande Plain, so that storage capacity for additional groundwater in this part of the basin is insufficient (1985c).

- The South County Area Plan (The Morro Group, 1990) recommended use of on-site or off-site retention/recharge basins capable of infiltrating 100-year storm runoff for parts of Nipomo Mesa that drain to the edge of the bluff. The basins could enhance recharge of the groundwater basin and also mitigate adverse erosion and sedimentation problems occurring at the edges of the bluff.

- Spreading grounds and percolation basins have been proposed for Santa Maria Valley by Santa Barbara County Water Agency (1994). The agency conducted a study that indicated a loss of about 17,000 AFY to the ocean with Twitchell Reservoir in place. Some of this water could be used to recharge the aquifer if sufficient spreading area and diversion facilities were available. The agency hypothesized that 3,000 AFY could be percolated to the groundwater basin using 400 acres of active spreading grounds.

Hydrogeologically, artificial recharge projects in the study area could be sustained. In Nipomo Mesa, a project (including *in lieu*) would be beneficial in alleviating declining trends in groundwater levels in some wells and associated loss in groundwater in storage that occurs in some parts of the mesa. The Nipomo Mesa portion of the basin has adequate space to store artificially recharged waters (only about 16 percent of its theoretical total storage capacity above msl is filled with groundwater). Potential development of this total storage capacity would be limited by the need to avoid groundwater leakage from the edges of the mesa. The high infiltration rates of the dune sands are favorable for artificial recharge projects. Identifying a source of water supply would be a foremost consideration for a recharge project on the mesa.

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